ON THE ATMOSPHERIC CHANGES WHICH PRODUCE RAIN AND WIND, AND THE FLUCTUATIONS OF THE BAROMETER.

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RAIN AND WIND,

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FLUCTUATIONS OF THE BAROMETER.

Second Edition,

WITH ADDITIONAL ESSAYS AND DIAGRAMS.

BY

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PREFACE TO THE FIRST EDITION.

For many years, Meteorological phenomena, in Lancashire and its neighbourhood, had engaged a portion of my attention. The winter of 1837-8, I passed in Rome and Naples, where my thoughts were directed to the climate of those places; and on my return to England, I determined to make inquiries into the causes which produce the atmospheric peculiarities of those parts. What I met with in books, written professedly on Meteorology, appeared obscure and unsatisfactory; and I resolved to employ a portion of my leisure in collecting, from travellers, facts likely to throw some light on the subject, and particularly to endeavour to trace the laws of nature in the department of Meteorology, where she operates on a large scale: believing that, in treating on so moveable a body as the atmosphere, that was the best course to adopt, in order to see the separate working of each cause.

The facts collected in this way at first appeared little better than a mass of contradiction and confusion; but, by putting them into the form of tables, and constructing charts and diagrams, to assist the mind by presenting pictures to the eye, slowly and gradually the influence of general principles appeared as pervading the whole. The facts which were apparently opposed to those principles were then subjected to a more careful examination, and the result was an arrival at the conclusions presented in the following pages. Some of these conclusions were, from time to time, communicated to the Manchester Philosophical Society, and they are now submitted to the public. If they have truth for their basis, they will, probably, be adopted by others; if they have not, I shall only add one to the list of those who have failed in attempting to explain the causes which determine the movements of the atmosphere.

PREFACE TO THE SECOND EDITION.

It is nearly ten years since the first edition of this work was published, and in the intervening period a number of important Meteorological registers have been communicated to the world. Many of these I have examined, with the view of tracing the laws which pervade the phenomena exhibited in them. Works of navigators, and other travellers, have also been read, and meteorological facts found in them collected and tabulated. Some of the results thus obtained are given in the Essays which are added in the present edition. In these Essays, the laws which pervade and govern our atmosphere, and which produce the great changes that are so constantly taking place in it,* are discussed more fully than had been previously done; and an attempt has been made to exhibit those laws in action in various localities.

Until lately, the laws that are in operation in this department appeared to obtain attention from Meteorologists; but at present their industry seems to be directed almost exclusively to the collection of facts. The great number of these, however, already furnished, justifies and invites an effort to discover the laws which govern the facts; this has been the object aimed at in the present work,—with what success, the reader may judge.

It was my good fortune to be acquainted with the late Dr. Dalton, who directed my attention to the mechanical intermixture of the constituents of the atmosphere, and to the different laws of cooling by expansion of the gases and aqueous vapour of which it is composed; and much of that which is advanced in this work, on the changes that take place in the atmosphere, is only a development of phenomena which are consequent on the laws discovered by Dalton, to whom meteorological science is largely indebted.

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ON

ATMOSPHERIC CHANGES.

The Constitution of the Atmosphere, and the Production of Rain and Wind.

The aërial ocean that covers the earth, and in which we live, is known to be composed principally of two gases, nitrogen and oxygen, in the proportions of about 79 and 21 in 100. In addition to these there is a small portion of another gas, carbonic acid, computed to be about as 1 to 1,500; and as these gases are not condensable, except at very low temperatures or great pressures, they are commonly called non-condensable gases. They are not united by any chemical affinity, as they intermix in the proportions named, or in any other proportions, with equal facility: they are, therefore, to be considered as diffused through each other mechanically, although found in about the same proportions in every part of the world within a moderate distance from the surface.

These proportions are, however, to some small extent, disturbed by local absorption or generation, and these disturbances are reädjusted by the process of mechanical diffusion. But between the generation or the absorption of the gases in particular places, and their complete diffusion through each other, to establish the uniformity of proportions in every part,

time will elapse, and the length of time required for the operation becomes a consideration of some importance. Were a quantity of oxygen gas liberated in a vacuum, it would, in consequence of its elasticity, expand with a certain degree of velocity, determined by its force of expansion, and this may be called its law of expansion. But if the same gas were liberated in a space occupied by another gas, say nitrogen, of a certain degree of density, the oxygen gas would still expand and diffuse itself through space and through the nitrogen; but, as it would encounter the particles of nitrogen in its progress, it would be impeded in its expansion, and would occupy a longer period of time in effecting it. The rate of expansion in the former case being known, it would express the law of expansion, and if from this rate we could deduct *the amount of the impediment encountered*, we should have the law of diffusion.

The law of diffusion of gases is of considerable importance. During combustion, when our furnaces unite that part of the oxygen of the atmosphere which is in immediate contact with heated fuel with a portion of the fuel, in the absence of draft, it is diffusion which causes a fresh supply of oxygen to press on the remaining fuel to continue the process of combustion: but the supply of oxygen is much less than it would be if that gas were unmixed with nitrogen, as then the oxygen would be supplied according to the law of expansion, and not according to the law of diffusion. The diffusion of gases, as distinguished from expansion, is, therefore, an important process, viewed only in reference to the movements of the non-condensable gases, which constitute the greater part of our atmosphere.

But there is another gas, or aëriform substance, in the atmosphere, called aqueous vapour, or steam, which is condensable at a comparatively high temperature, and the law of diffusion acting on this gas produces peculiar effects on the atmosphere. Aqueous vapour, unlike the non-condensable gases, exists in the atmosphere contiguous to the earth's surface, in the various

parts of the world between the equator and the poles, in very different proportions to the other gases. In some parts, near the equator, vapour constitutes $\frac{1}{48}$th part of the whole atmosphere, and this is when the point of condensation of some of the vapour, or the *dew-point*, as it is commonly called, is as high as 80° of Fahrenheit. In other parts, at certain distances from the equator, it is say $\frac{1}{60}$th of the whole, and the dew-point is at 73°. Proceeding towards the polar regions the dew-point is found to be respectively at say 52° and at 32°, and the vapour will then form not more than $\frac{1}{120}$th and $\frac{1}{240}$th parts of the whole atmosphere. There are situations where the temperature is, at times, as low as 90° or even 100° below the freezing point of Fahrenheit, and where, consequently, there must be very little vapour in the atmosphere. But as the law of diffusion will cause the vapour which is in superior abundance in one part to expand in the direction in which it is deficient in another, there must be a constant expansion and diffusion of vapour from parts where it is freely produced to other parts where it is comparatively deficient—from the tropical to the polar regions, and from one locality to another, producing peculiar effects, resulting from the condensability of this aëriform substance. The diffusion of any one constituent of the atmosphere must produce, to some extent, a movement, not of that gas alone which is diffusing itself, but also of those which it encounters, impinges upon, and carries along with it; and although aërial movements or currents, produced in this way, are generally feeble compared with those produced from other causes, hereafter to be noticed, yet they may, by bringing other causes into operation, be instrumental in creating more powerful currents, and will, at all times, more or less modify those which exist.

It has been long observed that there are streams or currents in the atmosphere, extending over large portions of the globe, which are evidently produced by causes acting with a certain

degree of force and constancy; and various speculations have been entered into, and theories formed, to account for these currents, or winds, but the theory now generally recognized is that which was first promulgated by Hadley, and may be described as follows:—

The sun's rays heat the surface of the globe within the tropics more than they do the surface of the temperate and polar regions, and the superior heat is communicated to the air resting upon the surface. The heated air then expands, rises, and flows over, at some certain height, towards the cooler regions, where it becomes itself cooled, and returns, as a lower current, to the tropical part, there again to undergo the same process. But these two aërial currents do not move from the tropical towards the polar regions, and back towards the tropics, in direct lines, as they are modified by the rotatory motion of the earth. This motion is, at the equator, say 1,000 miles an hour, and it becomes less towards the poles, until at each pole it is nothing. Consequently the upper current, from the equator, when proceeding towards either pole, will have a more rapid rotatory velocity, from west to east, than the part of the globe over which it is passing, and it will, relatively to the surface of the globe, to some extent, become a western current, or west wind: the joint effect of the two causes making it, say, in the northern hemisphere, a south-west wind. The lower air, which is passing from the poles towards the equator, will be affected in the reverse order, and from a north will be converted into a north-east wind. The same causes produce the same kind of effects in the southern hemisphere. This theory of winds, originally advanced by Hadley, has been recently maintained by Dr. Dalton, and is now generally recognized as true. Malte Brun, in his Geography, adopts it, and Professor Forbes, in his Report on Meteorology, in the transactions of the British Association for 1841, treats it as the established theory.

That the effects of the unequal heating power of the sun

on the surface of the globe, and of the varying rotatory velocities of the different parts of the earth between the equator and the poles, must be of the nature described in this theory, is sufficiently evident. But it is not equally evident that the causes pointed out are adequate to the production of those general winds which are known to exist. The difference in the rotatory velocities of different latitudes must certainly have the kind of effect described upon any winds which pass from the equator to the poles and from the poles to the equator, and the degree of effect will be proportioned to the rapidity of the passage of the wind from one latitude to another. But the unequal heating of the surface of the globe, and, consequently, of the air near it, by the sun, does not, as will be hereafter shown more fully, produce those palpable or strong winds which blow in some parts towards, and in other parts from, the tropics. The heating of the surface of the globe, and of the air near it, by the sun, is not a sufficiently powerful cause to produce those winds, though, like the law of diffusion, such surface heating may, and no doubt does, to a certain extent, bring into active operation another and a more powerful cause, and, as we shall see hereafter, one that is fully adequate to their production.

Unequal temperature is undoubtedly the great cause of the movements of the various portions of the atmosphere which constitute winds, but inequalities of temperature in our atmosphere are not produced merely by the partial heating of the surface of the globe, and of that portion of the air which is in immediate contact with it. The heat of the sun acts in two ways on the surface of the globe; one is by attaching itself to the matter of the earth's surface and increasing its temperature, which increase of temperature is, to some extent, communicated to the air which rests upon it, as stated in Hadley's Theory of Winds. But there is another way in which the heat of the sun acts: it unites with water,

and, by evaporation, forms aqueous vapour, without raising the temperature of the surface where the evaporation is carried on to the same extent that the temperature of dry land is increased: and the heat, thus united to the water, moves away from the part in the vapour, and, through the operation of certain causes, is carried to a greater or less distance, where it is liberated, and produces effects which appear to have been, in a great degree, overlooked by writers on this subject, but which effects must be duly estimated if we are to understand the causes of the winds which are found to prevail in various parts of the world.

In the following pages it is proposed to show that the heat which is thus taken up by vapour, in the process of evaporation, is carried away to various parts of the atmospheric regions, and in those parts is liberated on the vapour being condensed; and that it is this liberated heat which produces that inequality of temperature which causes the greater part of those aërial movements called winds on different parts of the surface of the globe. The limited power of surface heating in producing winds will be hereafter shown. At present we proceed to consider the evaporation of water by the sun's heat, and the consequent formation and diffusion of vapour; and the subsequent condensation of that vapour, and the liberation of the heat.

It is well known that, by placing water in a suitable vessel over a fire until it be sufficiently heated, a part of the water will rise from the surface in the form of vapour; and if this vapour, by a proper apparatus, be conducted to a cool part, it will be condensed into water; and the quantity of heat which had been taken up by the vapour, in the process of evaporation, may be measured by the progress of time, or the consumption of fuel. The quantity given out in condensation may also be measured by increase of temperature communicated to another body. And it is found that the quantity of

heat given out in condensation is precisely the same as that taken up by evaporation—none of it is lost, though, when united with water to form vapour, it may be conveyed from one locality to another. This course of evaporation and condensation is familiarly known in numerous processes and works, where the heat from a fire is made to vapourise water in a large boiler, which vapourised water is, by its own condensation, made to heat water in other boilers. Now the heat of the sun, if applied to water by a proper apparatus, would have precisely the same effect as the heat of the fire. The solar heat would raise the temperature of the water, vapourise it, and would be given out to any other substance, on condensation being effected, just as the heat from the fire is known to pass through those various stages. And it is not at the temperature of boiling water alone, that heat may be taken up by evaporation and given out by condensation. Water may be vapourised by heat, at either higher or lower temperatures, the quantity being proportioned to the heat expended; and an exposure of the vapour to lower temperature will condense it. Thus, vapour of 250° of Fahrenheit, if turned into air or water of 212°, would be in part condensed. And vapour of 212°, if allowed to flow into a temperature of 200°, would also be in part condensed into water, and in like manner in other lower degrees. Atmospheric vapour, rising from water of the temperature of 80°, which is common within the tropics, would be in part condensed if it came immediately into contact with water of the temperatare of say 70°. Vapour from water of 70°, 60°, 50°, 40°, or 32°, would be condensed if exposed to or brought into contact with temperatures below those respective degrees. And even from ice of 30° or 20° of temperature vapour may arise which can be condensed by exposure to lower temperatures. In all these cases the heat taken up by the vapour in evaporation, is given out by condensation wherever the condensation takes place; and wherever the heat is so given out, it raises the temperature of the part,

and generally of bodies in the part, in proportion to the quantity given out; just as vapour from one boiler gives out its heat, on being condensed, to the water of another boiler, and raises its temperature. The following tabular view will exhibit the comparative quantities of heat expended, as measured by time, in converting ice of low temperature into vapour. And if we suppose a process the reverse of this to take place, the heat expended would be given out, and would, allowing for alteration of capacity, proportionally raise the temperature of anything that should receive it. Suppose a vessel, with pounded ice in it, of the temperature of 0° of Fahrenheit, to be placed over a burning jet of gas, of uniform strength, and the times noted in the table will mark the relative quantities of heat required to effect such alteration of the ice, until it is converted into vapour:—

Seconds of Time.	Quantities of Heat.	Increase of Temperature.	Heat Absorbed.
0	0	0°	
32	32	32°	
140	140		140 Liquidity.
180	180	180°	
1000	1000		1000 Elasticity.
1352	1352	212°	1140 Latent.
			212° Temperature.
			1352 Total.

Here we see, that whilst 1,352 of heat was expended, only 212 of it went to raise temperature, leaving 1,140 of latent heat, 1,000 of which, on condensation of the vapour, would be given out to any cold substance with which it was in contact, and consequently might be given to the atmosphere.

The sun is the great source of heat on the surface of our globe, and over a large part of the globe the solar heat is regularly uniting with water, from the surface of both land and sea, and vapourising it. As the vapour is formed it

acquires elastic force, and springs into the atmospheric space above the surface, and this evaporation is disposed to proceed until a maximum quantity of vapour is formed, which is proportioned to the temperature of the part. The maximum is one quantity within the tropics, where the temperature is high, and other quantities at different distances from the tropics, where the temperature is lower; but owing to certain causes, which it is not necessary now to explain, it is seldom that the maximum quantity is found in the lower levels of the atmosphere, as condensation in one place is reducing the quantity almost as regularly as evaporation in another place is increasing it. But, wherever condensation takes place, there the solar heat, which had been united with the water to form vapour, is given out, and the temperature raised, and the air in the part warmed.

There are parts within the warm regions of the tropics, where evaporation proceeds until there is so large a quantity of vapour in the atmosphere as to admit a temperature of, say, 80° to condense a part of it, and where, consequently, the dew-point is 80°, that being then the point of condensation. The atmosphere itself may be 81°, or 85°, or 90°, but no higher temperature than 80° will condense any portion of the then existing quantity of vapour. In cooler regions evaporation cannot so fully charge the atmosphere with vapour, as, if evaporation were to take place at the surface—the cold above would condense a part of the vapour as rapidly as it was formed. There are parts where the dew-point is not higher than, say, 70°, because the cold there condenses a portion of the vapour, whenever it is supplied in additional quantities by evaporation from wet surfaces. In other parts the dew-point does not rise higher than 60°, 50°, 40°, or 30°, in the cold season. Now, if a part of the atmosphere, fully charged with vapour, should, from any cause, be conveyed from a warm to a cold region, a portion of that vapour would be condensed, and fall as rain. And it is sufficiently evident,

that either the process of diffusion, or the unequal heating of the surface of the earth, and, consequently, of the air resting on it, is capable of conveying warm and moist air into a colder *region than that in which it had received its* large amount of moisture. And in this way an atmospheric current, proceeding from warm to cool latitudes, may produce condensation and rain.

But there is another cause of condensation of atmospheric vapour, more active and powerful in producing that condensation than change of latitude, which cause is the raising of a part of a moist atmosphere to a greater elevation than that in which it had previously existed. In an atmosphere at rest, it is found that the temperature diminishes, say, about one degree for every 100 yards of elevation; and this is attributable to the inferior density, and consequent increased capacity for heat, of the atmosphere, arising from the diminished pressure of the portion above. Now any part of the air of the lower region being raised 100 yards, would be subjected to less pressure, and would, consequently, be cooled, say, about one degree. On being raised 200 yards, it would be cooled two degrees; 400 yards, four degrees; and so on in proportion to the height. And as there are causes in constant operation, sufficiently powerful to produce movements of the atmosphere, those causes may force currents of air to ascend the sloping sides of ridges of mountains, and thus to become cooled by elevation, and have a part of their vapour condensed by that cooling. The elevations of land are extremely irregular, and currents of air being impelled against those irregularities, would follow their courses, and might, consequently, encounter each other; and some, by forcing their way near the surface of the land, might raise other aërial currents, and thus cool them in a greater degree, and produce more abundant condensation.

The air in the lower region of the atmosphere may also be raised by the action of the sun on the surface of the globe.

When the morning sun warms the surface of the earth, that warmth is communicated, to some extent, to the air in the immediate vicinity of the surface, which expands and rises; and, the action being continued, ascending columns of warm air are formed, which may rise sufficiently high to be cooled to that degree which will produce condensation of a part of the vapour that the air contains. The same process may take place over the sea, all that is necessary being that the air near the surface be adequately heated, as compared with the general temperature of the atmosphere in the vicinity, to produce an ascending current which shall carry the air within it sufficiently high to condense vapour.

But, judging from what takes place on the earth, it may be truly said, that if no other cause of rain or wind existed, than those yet named, there would be no copious rain, nor stroug wind, in any part of the world, as these causes would evidently all operate mildly and gently. Inequality of temperature, on different parts of the earth's surface, in no place directly produces a strong wind, though there are parts where that inequality is great within small distances. And as ordinary cooling of air, saturated with vapour, takes place slowly, condensation would be slow, and only slight rain would fall, were there not another and a more powerful cause at work, to produce that copious condensation and those strong winds which are experienced in many parts of the world. This cause may be shown to be in operation when currents of air are forced up mountains, or when they force up each other; but we will at present trace it as arising from the action of the sun on the surface of the globe, be that surface either land or water.

The sea, say in the neighbourhood of the British islands, furnishes, by evaporation, a supply of vapour to the atmosphere sufficient to charge it so fully, for the temperature, that to cool it in a small degree will cause condensation of a part of the vapour which it contains. When the morning sun warms the lower part of this atmosphere, it rises, and the

process being continued, at some certain height, the upper part of the ascending column of air is sufficiently cooled to cause condensation to begin, and minute particles of water to be formed, and thus condensation takes place from the ascent and consequent cooling of the atmosphere. The result of this amount of condensation would, however, be, as already stated, only a small and continued rain; but through the influence of another cause, which now comes into operation, that rain may be made abundant.

On condensation of vapour taking place in the ascending air, heat is liberated, or given out, as has been shown to be the case whenever vapour is condensed; and the liberation of this heat has, at first, a tendency to prevent further condensation, by raising the temperature of the remaining vapour. But the liberated heat raises the temperature not only of the remaining vapour which is in the raised air, but of the air itself also; and the increase in the temperature of the air has an important influence in producing subsequent results.

The amount of vapour in the atmosphere is indicated by the dew-point, and the higher the dew-point the greater is the quantity of vapour. The following tabular representation will point out the ordinary quantities commonly met with on different parts of the globe:—

Dew-points at degrees of Fahrenheit.	Proportional parts of Vapour in the Atmosphere.
32°	$\frac{1}{140}$th
52°	$\frac{1}{120}$th
73°	$\frac{1}{60}$th
80°	$\frac{1}{45}$th

Supposing then the dew-point to be at, say, 56°, an ordinary height in our summers, we shall find that the vapour will constitute not more than $\frac{1}{100}$th part of the whole atmosphere,

the remainder being formed of non-condensable gases. And as the vapour and gases are intermingled, and diffused through each other, the liberated heat produced by condensation would be attached to the gases and the remaining vapour, say in proportion to their respective quantities, that is, ninety-nine parts of the liberated heat would be attached to the gases, and only one part of it to the remaining vapour. The gases would thereby have their elasticity increased—they would expand and rise to a greater elevation, and the remaining vapour, being entangled with them, would be carried by them to a higher, and consequently to a colder, region. In that higher and colder region the same process would be repeated, vapour would be again condensed, heat liberated, the gases warmed and expanded, and another similar process commenced; and these processes would be continued as long as there was a sufficient supply of vapour from below to feed them. The rapidity and energy of the process would depend on the extent of the supply of vapour, and of the power of cooling it. When the supply of vapour was small, and the higher part of the atmosphere warm, the process would be slow, and a mist or stratus cloud would be formed; when the vapour was more abundant, and the higher parts of the atmosphere colder, the process would be more rapid, and cumuli might form, and *rain* fall.* And if the supply of vapour was great, and the higher parts of the atmosphere very cold, the process would be violent, and heavy rain would be produced. It is, then, to the action of the liberated heat on the gases, and their mechanical action on the remaining vapour in carrying it into a colder region, that we are to attribute that energetic operation of condensation, which produces such important effects in the movements of the atmosphere, as those which we shall have to point out.

In the construction of the air thermometer, it has been

* The formation of the cumulous cloud was explained in a paper inserted in the Philosophical Magazine for August, 1841.

found necessary to ascertain to what extent the air expands by an increase of temperature—and it is found to be $\frac{1}{480}$th part of its bulk for each degree of Fahrenheit. An increase of the temperature of a particular mass of the atmosphere, to the extent of only one degree, would, therefore, by augmenting its bulk $\frac{1}{480}$th part, without increasing its weight, give it a decided buoyancy, and the adjoining heavier air would press it upwards. A local increase of temperature of, say two, four, or six degrees, would of course give much greater buoyancy to the mass, and cause it to be forced upwards with greater rapidity.

Heat is undoubtedly the great agent in producing atmospheric movements, and it is, we have seen, occasionally conveyed in vapour to particular heights in the atmosphere, where it is liberated by the condensation of the vapour. Now vapour, at a certain height, which, on being condensed, will form a cubic foot of water, liberates heat enough to expand the atmosphere with which it is in contact, say 8,000 feet. On the weight of this column of air being thus made less than that of the adjoining columns, contiguous air would press in to fill up the comparative vacuum, and would become an ascending column similar to heated air in a chimney. For, the adjoining air being equally charged with vapour, would, when it reached an adequate height, have its vapour also condensed, furnishing more heat; and the process might be continued as long as there was a sufficient supply of vapour. In this way it will be perceived that the vapour which is diffused through a large extent of the atmosphere, and which, with a dew-point of, say 56°, constitutes only $\frac{1}{100}$th part of it, may be brought successively from a wide space to a particular locality, where much rain may fall. And the same process may take place with other dew-points than that named, producing copious rains where the dew-point is high, and moderate showers where it is low.

The different laws of cooling of the non-condensable gases

and of vapour produce important effects in the atmosphere. On removal of incumbent pressure, and permitting expansion to take place, the gases cool, say, 5°, whilst the vapour would cool only 1°. Through the operation of these different laws of cooling, the non-condensable gases, in their ascent to a height of, say, 500 yards, will cool 5°, whilst the vapour that is within them is disposed to cool, by its own expansion, not more than 1°; but as the different gaseous substances are intermingled, the cold of the former is communicated to the latter, and the vapour is condensed, not by the cooling consequent on its own expansion, but from that which results from the expansion of the gases! When evaporation of water from the surface of the globe takes place, in a previously dry atmosphere, the vapour, as it is formed, by its elastic force rises into the atmosphere, and would, by its own law of cooling, have its temperature reduced only 1° for every 500 yards of height to which it might ascend; but it has to expand into, and pass through, the interstices of the gases, which have a temperature that is found lower by 1° for every 100 yards of height. The vapour, in rising, is consequently cooled by the cold gases into which it has to expand, and thus condensation commonly goes on at some moderate elevation in the atmosphere, whilst evaporation is proceeding on the surface below. The condensation forms cloud, and warms the atmosphere in the part, and, generally, it will be found that the temperature in the newly-formed cloud will be only about one-half as much reduced by altitude as that of the neighbouring air, which has been undisturbed by recent condensation:—that is, in newly-formed cloud the temperature will be lower only half a degree for every 100 yards of height, whilst in clear and undisturbed air it will be one degree lower at the same height; the cloud will, consequently, be lighter than the adjoining air, and will be liable to be pressed upwards by the superior weight of the *cool air, and may form an ascending current. When the atmosphere* is thus heated, raised, and expanded in a particular

locality, the adjoining more dense air presses into the comparative vacuum, and being in its turn heated, and a continued ascending current created, more distant air rushes in, and thus a horizontal current of air is produced, and *a wind* is the result—and this wind is feeble or strong according as condensation is moderate or energetic.

It having appeared obvious that the gradual cooling of the atmosphere, by passing from a warm to a cool latitude, could not produce such rains as frequently fall to the earth, a theory has been advanced—first, by Dr. Hutton, to account for those rains, which has had the powerful support of Dr. Dalton. This theory teaches that "when two currents of air, of different temperatures, both fully charged with vapour, are intermixed, a mean temperature of the two is obtained. But this mean temperature will not admit the same quantity of vapour to exist in the elastic form, in the mixed air, as that which had been contained in the two separate currents, with the two temperatures; a part of it is, therefore, condensed, and falls as rain."

After explaining this theory, Dr. Prout says, "It must, however, be allowed, as we have before stated, that the utmost information which we can at present bring to bear upon the subject of the general condensation of moisture from the atmosphere, and of rain in particular, leaves it involved in considerable obscurity."*

With reference to this theory it is sufficient to observe, that masses of air cannot intermix intimately, as is here assumed, except by a slow process, and that process could not produce such falls of rain as very frequently occur. Different gases diffuse themselves through each other with less or more rapidity, because such gases are merely temporary impediments, and not barriers, to the passage of each other; but any one gas is a barrier to the penetrating power of the same kind of gas. A mass of oxygen, by its elastic force, does not

* Bridgewater Treatise: Chemistry, Meteorology, &c. Page 327.

penetrate another mass of oxygen, any more than one mass of water penetrates another mass of water which presses against it; and therefore, when two masses or currents of oxygen of different temperatures come in contact, they are disposed to arrange themselves in their masses according to their densities, and not to penetrate each other. The outer parts may indeed be conceived to penetrate each other to some small extent, but they evidently could not proceed so far as to produce extensive condensation. The same remarks will apply to nitrogen gas and vapour, because each of these aëriform substances is equally unable to penetrate a mass like itself. But, though intermixture cannot produce that extensive condensation which must take place when heavy rain falls, if two masses of the atmosphere of different temperatures, fully charged with vapour, should strike or press against each other, whilst moving, the process of condensation may be thereby commenced at their lines of contact. And when the process is in this way begun, it may be continued through the agency of ascending heated air, as already explained.

For our present purposes, clouds may be divided into three classes—the stratus, the cumulus, and the cirrus. The stratus is formed simply by condensation, and may be seen in this part of the world in the morning, generally resting on the surface of the sea, and frequently on the land in the summer and autumn. At these times the surface of the globe, particularly during the night, is warmer than the air, and the vapour of evaporation, as it rises in the cold air, is slowly condensed into small particles of water, which form a fog or stratus cloud. This cloud may also be formed by the contact, or slight intermixture of currents of air of different temperatures, which are fully charged with vapour. On the stratus being, from any cause, raised to a sufficient elevation, it may, by a more energetic action of condensation, be converted into a cumulous cloud, with an ascending aërial current, forming conical tops; which current may also bear the cloud to a great height.

When the cumulus is borne to as great a height as the supply of vapour from below will carry it, and when the ascent of the current, resulting immediately from condensation, ceases, it is evident that the liberated heat which it contains may have made the cumulous cloud warmer than the adjoining atmosphere at the same level. And that adjoining atmosphere, being dry as well as cold, may, in pressing up and following it, cease to supply vapour to the cumulus, although that cloud may, through the superior warmth which it retains, continue to ascend. It will become somewhat like a fire-balloon, having warmer and therefore lighter air than that in which it floats; and in this state it may rise slowly to an *additional height. It will not*, however, now have the swelling conical top of the cumulus, but will become a mass, the outer parts of which will begin to dissolve by evaporation. Or should it meet with different currents of air, it may be elongated or torn in pieces, the outer edges of each piece being dissolved by evaporation, when it would become the cirrus or hairy cloud. The interior portion of these cirri having innumerable small particles of water from which to furnish vapour by evaporation, will, for a time, have their maximum quantity of vapour for the temperature; and the diffusion of this vapour will be more or less rapid as the adjoining air is more or less dry. As these clouds, or pieces of cloud, lose their warmth, they will descend to a lower stratum, when they will rapidly dissolve. But it is evident that such clouds may, for a time, form warm beds or strata, at different heights in the atmosphere, or may, by evaporation, greatly cool the locality, and when the whole is in motion, with currents moving at different heights in various directions, may produce an indefinite variety of results.

Writers on climate commonly distinguish between the hot and dry and the hot and moist, and this distinction, founded on experience, is connected with the separate causes that produce the two climates. The hot and dry is produced by

the direct action of the rays of the sun on the surface of the earth, warming it and raising the temperature. The surface of the ground is found occasionally to be from 100° to 150° Fahrenheit, whilst the sun pours his heat on the land through an unclouded sky. At night, however, the temperature sinks, the heat being apparently carried away by the air or lost by radiation. The deserts of Northern Africa, Arabia, and Persia, are samples of this climate. The hot and moist climate is not produced by the sun's rays heating the surface of the earth, but by the heat which is liberated on condensation of vapour being effected. The sun is the original source of this heat also, but this is first united with water, and the two form vapour, which is frequently carried to parts far distant from the place where the solar heat united with water to form the vapour, and in these distant parts the vapour is condensed and the heat which it contained liberated, making the part hot and moist. The Caribbean Sea, the Bay of Panama, Hindoostan, and the west coast of tropical Africa, are places possessing the hot and moist climate; and there are other parts of the world which partake of the nature of each of these two climates in various degrees.

When condensation of vapour causes air to ascend and other air to rush into the vacuum thus formed, we have wind created from a source other than the partial heating of the earth's surface by the direct rays of the sun, and it becomes an object of inquiry to ascertain what winds are produced by the one and what are produced by the other cause. And in order to accomplish this we will endeavour to trace out those general winds or great atmospheric currents which are known to exist, mark their meteorological and other peculiarities, and note various accompanying circumstances by which they are distinguished, that we may, if possible, discover the real cause that is in operation to produce the wind in each case. By adopting this course we shall bring facts to bear on theoretical reasoning, and make them test its soundness; whilst

province of Guayaquil, near to the equator, where rain falls freely, but as it approaches this part it appears to spread out to the west. And when it reaches the Galapagos Islands, six hundred miles from the continent, it becomes nearly an east wind.

As there is no north-east trade wind in this part in the northern hemisphere, the south wind, just described, seems to be the only source of supply of the tropical trade wind in the Pacific Ocean. C. Darwin, speaking of it, says—" Oct. 20th, sailed from the Galapagos, and in the course of a few days got out of the gloomy and clouded region which extends, during the winter, far from the coast of South America. We then enjoyed bright and clear weather while running along pleasantly at the rate of 150 or 160 miles a day, before a steady trade wind." The distance to Tahiti is 3,200 miles. " The temperature, in this more central part of the Pacific, is higher than near the American shore. The thermometer in the poop cabin, both by night and by day, ranged between 80° and 83°."*

In this part of the Pacific the trade wind is found to extend nearly from tropic to tropic, and is generally steady, excepting where it encounters islands. Abundance of vapour exists in it, and when circumstances occur that condense any considerable portion of this vapour, the regularity of the trade wind is disturbed. The dangerous archipelago is in about 140° of longitude and 20° of south latitude, and these islands are one of the first groups the trade wind encounters after leaving the neighbourhood of South America. Captain Fitzroy says, when speaking of this part—" Singular interruptions to the trade wind occur in the low lagoon islands of the dangerous archipelago. Not only does the eastern wind often fail among them, but heavy squalls come from the opposite direction."

The Society Islands are further west and a little more north. Some of these are lofty, and the same kind of disturbance of

the trade wind is found among them as in the low islands of the dangerous archipelago. Captain Fitzroy says—"From the latter end of December to the beginning of March, cloudy weather, with much rain and westerly winds, is usual at Otaheite;" and he adds, "Singular interruptions to the regularity of the trade winds occur among all the tropical islands of this ocean."* The Marquesas Islands are affected in a similar way to the Society Islands.

The Pacific, in the vicinity of the equator, on the northern side, is without islands, within the longitudes of which we have been speaking, and the trade wind is there more regular than on the south side. From the longitude of the Society Islands the wind proceeds, with occasional interruptions from various other islands, to the continent of Asia, and the East Indian archipelago. In Captain Cook's third voyage, when speaking of Otaheite, and the islands to the west of it, it is said that—"In December and January the winds and weather are both very variable; but it frequently blows from the west-north-west or north-west, and then is generally attended by dark cloudy weather, and frequently by rain. It sometimes blows strong, though generally moderate, but seldom lasts longer than five or six days without interruption, and is the only wind in which the people of the islands to the leeward come to this (Otaheite) in their canoes." This weather, it will be observed, prevails when the sun has reached its southern limit, and when evaporation must have pretty fully charged the southern atmosphere with vapour. At other times of the year the wind is different. In the same part of Cook's third voyage it is stated, that "the wind, (at Otaheite,) for the greater part of the year, blows from between east-south-east and east-north-east. This is the true trade wind, and it sometimes blows with considerable force. When this is the case, the weather is often cloudy, with showers of rain, but when the

* Voyage in the Beagle, &c., page 518.

wind is more moderate, it is clear, settled and serene." From the tenth degree of south latitude to the twentieth degree north, there are very few islands in the Pacific Ocean between the coast of America and the East Indian archipelago. In this vast space the eastern trade wind blows steadily, the disturbing influence of the islands within, or contiguous to it, scarcely affecting it. It was along this part that the Spaniards, in their early voyages, went from Acapulco to the Philippine Islands. But the eastern trade wind, so mild and steady in the open ocean, becomes disturbed as it approaches the islands of the Indian archipelago, where it assumes a different character.

In its progress westward it encounters the most easterly islands of the archipelago, and in this part of the tropical regions, both south and north of the line, the condensation of the vapour brought from the wide range of the Pacific produces very striking effects. Heavy rains fall, the regularity of the trade wind ceases, and winds blow in all directions, so as to constitute it a region of drenching rains and varying storms.

It thus appears that the atmospheric current which is found on the western coast of South America, and which blows from the south along Peru towards the equator, is first a dry and comparatively cool wind. As it approaches the Galapagos Islands it turns more to the west, and after leaving them it is found extending nearly from tropic to tropic, and blowing as an east wind. Among the various groups of islands to the south of the equator the regularity of its current is materially disturbed, more particularly at the period of the year when the southern atmosphere is the most fully charged with vapour. But on the northern side of the line, where the sea is quite open, it proceeds in an almost uninterrupted course from the Galapagos to the eastern archipelago. And among the various groups of islands which there lie, both north and south of the equator, the vapour which is brought by this atmospheric current is, to a great extent, condensed, producing copious rains, strong winds, and frequent storms.

In the broad expanse of the northern Pacific Ocean it does not appear that any atmospheric current flows from the north towards the tropics, in the lower part of the atmosphere, to constitute, or to add to, an eastern tropical trade wind. But in that part which is near to the eastern coast of Asia a cold wind is found. Navigators all agree that, in our winters, the whole of the coast extending from Kamtschatka to the south of China is very cold for the latitude, and also dry. La Perouse and others have given accounts of the intense cold of winter along this line; and Dobel, the Russian traveller, says—"Towards the last of September or the beginning of October, at Canton, the *Pak Fung*, or north wind, commences. This wind is so remarkable in its effects, and so immediately felt, that should it begin at night, even when all the doors and windows are shut, the extreme dryness of the air penetrates into the house immediately, and the furniture and floors begin to crack with a noise almost as loud as the report of a pistol."* This wind, in the winter, blows from Japan to the common terminus of all the winds in these parts, the Indian Archipelago, and is felt as far as the island of Borneo, and even to the Java Sea. Malte Brun, when speaking of the Philippine, Molucca, and Timorean chains of mountains, says—"In the western parts the rains prevail during the months of June, July, August, and part of September, the season of the west and north-west winds; and the adjoining seas are tempestuous, the lands inundated, and the plains converted into wide lakes. At this time the easterly and northerly parts enjoy fine weather. But in October and the succeeding months the north winds, in their turn, sweep the coast with equal fury, accompanied with an equal abundance of rain, and the same inundations take place, so that when the weather is dry in one district it is rainy in the other."

The condensation of vapour that passes from the north by

* See Dobel's Travels, vol. 2, page 195.

the China Sea is evidently effected about the islands of the Indian Archipelago, and, consequently, towards them this cold current flows as a north and not a north-east wind; whilst that part of the same great cold current which makes its way over central Asia to the Arabian Sea and the Bay of Bengal, into the Indian Ocean, and which is known as the north-east or winter monsoon, instead of continuing a north-east wind, turns and flows as a north-west wind to those same islands of the Indian archipelago, where its vapour, or a large part of it, is condensed.

Thus it appears, that condensation arrested the progress of the general tropical trade wind among the islands of the Pacific, and sometimes produced an opposite wind; that it caused a north instead of a north-east wind to blow over the China Sea, and converted the north-east monsoon into a north-west wind in the Indian Ocean. But if condensation can thus cause currents to deviate from their courses, or even reverse them, may not the same condensation produce the currents themselves? Reverting to the first case noticed—may not the condensation which takes place against the eastern side of the Andes, within the tropics, be a principal cause why the winds called the north-east and south-east Atlantic trades, prevail in their respective localities? Condensation, we have seen, is great on the eastern side of the Andes, and from that region whence the Amazon and the Oronoco are supplied with water, we may trace the drawing effects of that condensation in the two hemispheres backwards along the two lines of the trade winds to Madeira and the Cape of Good Hope.

Supposing such to be the operation, we may consider this tropical region an area or site of condensation of atmospheric vapour, which condensation creates an extensive ascending current in the atmosphere, and air not being able to come over the mountains from the west, the cold currents from both hemispheres press and flow from the east to furnish a fresh

supply of air and vapour. And the cold currents flow from great distances along particular channels, and not from other quarters, or along other channels, towards this area, because no disturbing causes sufficiently powerful interfere to divert them from those channels. Condensation in this region may thus be considered to act on the trade winds as a first moving power or a cause, drawing air towards a place where it is in active operation.

If this view is correct, we shall have to consider the different degrees of influence of the direct rays of the sun on surfaces of the tropical and polar regions, as but one of the causes of the great atmospheric currents, and that too the more feeble one; whilst condensation generally in the tropical regions, and in particular localities within them, will be another, and that the more powerful cause. Inequality of temperature being the great cause of all atmospheric movements, that inequality may be found to arise in a greater degree from condensation of vapour, than from the difference between the tropical and polar temperatures of the surface of the globe.

Within and near to the tropics the sun is constantly exerting its power, not only in heating the surface of the globe, but also in vapourising water, and the heat which was furnished by the sun during the process of evaporation, is given out when condensation takes place, and a general rise and overflow of the atmosphere in the tropical regions is the result. And if from local causes, such as the existence of elevated land, much condensation should take place in certain parts within the tropics, great heat must be given out in those parts, and the ascending currents would be there particularly strong. Now, the elevated ridge of the Andes, within the tropics, is evidently a local cause of condensaton, and as such produces an ascending current, which draws towards itself those portions of the atmosphere in both the northern and southern hemispheres that rest on low levels, and which are the least exposed to disturbing influences. It follows that, to the condensation

of vapour in this part of America we may attribute the existence of the north-east and south-east Atlantic trade winds.

The same kind of statement and reasoning will apply to the eastern trade wind of the Pacific Ocean. This wind, we have seen, terminates among the islands of the East Indian archipelago, where very copious condensation is known to take place. We may, therefore, consider the condensation of vapour, on the eastern side of the archipelago, a principal cause of the eastern trade wind which prevails in the tropical regions of the Pacific Ocean; and this cause in its operation extends backwards from the archipelago across the Pacific to America, and then, the mountains preventing any further supply coming from the east, southward along the coast of Peru. And thus these two localities, the Andes and the Indian archipelago within the tropics, become the sites of the active operating causes which produce the tropical trade winds.

That condensation of vapour, and not difference of surface temperature, is the principal cause of these atmospheric currents may be readily admitted to be possible, because we find that condensation is able to overcome the influence which is supposed to result from difference of surface temperature. Did the latter cause produce the currents, or were it the principal cause of their production, all north-east and south-east winds must have become east winds when they entered the low level regions of the tropics. This follows, as a necessary consequence, on Hadley's theory, because, on that theory, a north-east wind, from the north, and a south-east wind, from the south, when they reach the tropics, must take a course determined by their joint force, and, consequently, must become an east wind. But in the Indian Ocean, south of the line, there is a south-east wind which reaches the tenth degree of latitude, and to the north of the line a north-east wind, which blows from the continent of Asia, over the Arabian Sea and the Bay of Bengal, into the northern Indian Ocean; but those two winds do not join in the neighbourhood of the

equator and become an east wind, blowing on tropical Africa, as they would if the Hadleyan theory were true. No; so far from that taking place, we have seen that the very opposite result is experienced. The north-east wind turns round and flows back as a west instead of flowing forward as an east wind, and is finally absorbed in that ascending vortex which appears to exist over the islands of the archipelago. Here, then, we have an instance where the influence of condensation of vapour is opposed to that of inequality of surface temperature, and where the former is shewn to be the superior force. And if we are to attribute to condensation of vapour the prevalence of the north-west wind of the Indian Ocean, why should we not refer to the same cause the tropical east wind of the Pacific? The archipelago is placed within the tropics, with the Indian Ocean on one side to the west, and the Pacific Ocean on the other side to the east, and winds blow towards it from both sides—from the west and from the east; and why should we suppose a different cause to produce the wind on the one side, to that which evidently produces it on the other? There is no valid reason for such a supposition, seeing that condensation is quite as active on one side as on the other, and is as capable of producing the wind from the Pacific as it is that from the Indian Ocean.

And within the Pacific Ocean itself we saw that the small islands which are scattered over its immense extent, were able to disturb, and even to reverse the general winds, when those islands condensed an adequate amount of vapour. Both Captain Cook and Captain Fitzroy state that, when the southern hemisphere was fully charged with vapour, heavy rains fell about these islands, and the winds then blew towards them from the west, instead of blowing from the usual eastern quarter. And Captain Fitzroy says that, at the period of the rainy season, these westerly winds extended sometimes across the whole Pacific, by the dangerous archipelago, even to the coast of Guayaquil, when heavy rains fell in that part, fur-

nishing, in this reversal of the wind, another striking instance of the paramount influence of condensation of vapour in determining atmospheric movements.

It has been shewn that the general eastern direction of the tropical trade wind was reversed in the Indian Ocean, as a west wind blows from that ocean to the Islands of the eastern archipelago. But that is not the only part within the tropics where a west wind is to be be found. On the western coast of Africa, extending from 10° north to say 15° south, in the rainy seasons, westerly winds prevail, and they appear to be produced by the same causes as those which determine a west wind to blow on the eastern archipelago. There are, in the interior of Africa, not far from the equator, mountains sufficiently elevated to condense a large portion of the vapour which is there found to exist in the atmosphere. On the coast very heavy rains fall, as much, according to Major Tulloch, as 300 inches in the year having been observed in one part; and the interior is known to resemble the coast in this particular. In some maps, one locality, near the equator, to the south, is marked as having perpetual rain. This region of condensation extends, in the interior, to the 15th degree of south latitude. In this part condensation of vapour apparently reverses the general eastern direction of the tropical atmosphere, as, during the rains, a north-west, west, or south-west wind is found to blow. The copious condensation extends to only about 15° north—beyond that little rain falls. Presuming these rains to fall south or north of the line, according to the position of the sun throughout the 30° of latitude named, we have a sufficient cause for the westerly winds which prevail on the coast. In the interior of Africa, as over the East Indian archipelago, condensation of vapour produces ascending aërial currents, and the western winds blow to feed them, in these parts of the tropical regions.

Another of these winds, although it is not confined to the tropical regions, is the south-west monsoon of the Indian

Ocean and parts adjacent. It has been shewn that, in the winter, a north-east wind blows over central Asia, the Arabian Sea, and the Northern Indian Ocean; in the last-named part becoming a north-west wind by bending eastward towards the eastern archipelago. But shortly after the sun has passed the equator, to move farther northward, condensation takes place freely on the north side of the line, and it is earliest in the most elevated parts that are near to the line. At the same time the south-west monsoon begins to blow; and, as the sun advances north, condensation in the locality increases, and the monsoon blows more fiercely. The period of the greatest condensation is when the action of the sun has caused the greatest evaporation in the northern hemisphere, and furnished the greatest abundance of vapour north of the line. At this time the south-west monsoon rages over the whole of that part of the surface of the globe which is included between the equator and the Himalaya mountains, and along the coast of China, and between say the 50th and 120th degrees of east longitude. Over this space the summer monsoon blows with various degrees of force, and rain falls in various degrees of abundance; the strength of the wind appearing to bear a constant relation to the amount of rain. It has been stated that in a part of the ghauts upwards of 302 inches of rain have fallen in a year. In the *Bombay Times*, of August 19th, 1840, is the following account—"We have just heard of a most enormous fall of rain at the Mahabaleshwar hills, amounting, since the beginning of last month, to no less than 134 inches! The greatest fall in one day is 12¾ inches. This is very much beyond the ordinary quantity for the rainy season at the hills, though the fall there does at all times greatly exceed that at Bombay." But a very large amount of condensation also occurs against the south-west side of the Himalaya mountains, where the heavy rains feed the Indus, Ganges, and Burhampooter. I have not met with any account of the quantity of rain that falls against these moun-

tain, but it must be great. Major Archer says—"Barr is sufficiently elevated to see over the outer ridge into the plains. In the rains neither man nor beast can inhabit it; even the dāk, or post-runners, are obliged to be changed often, owing *to attacks of fever."* These rains are not confined to the plains, or the low hills just above them,* but fall freely among the mountains. Malte Brun, in his Geography, says—"In the interior and western part of India the rainy season commences in April or May, and continues to the end of October. On the Coromandel coast it begins later, as the clouds which are brought by the south-west winds are detained by the ghauts. While this season lasts it is a rare thing to see the rays of the sun penetrate the dense vapours with which the atmosphere is loaded. In Bengal it rains incessantly for many days. Twenty or twenty-two inches depth are computed to fall in a month."† "The Ganges rises 15 feet by the end of June. By the end of July all the low adjoining land is flooded." The great amount of condensation in this part sufficiently accounts for the fierce storms which occur there, and they extend to the China Sea, where they are called typhoons.

The cause of the south-west monsoon is generally said to be found in the heating of the continent of Asia by the sun's rays; this, however, cannot be the cause, as we know that Hindoostan is covered with clouds during the rainy season, but the facts already given furnish sufficient evidence that condensation of atmospheric vapour is an adequate cause. And we may, therefore, conclude that the great condensation which takes place in this region produces ascending aerial currents, and, as a supply of air cannot cross the mountains from the north, the air from the equator rushes in, and produces the south-west monsoon. It will hereafter be more

* Archer's Travels, page 207.

† Malte Brun, vol. 3, page 25

fully shown that sun-heated lands do not produce such winds. If they could, the heated land of tropical Africa would draw towards itself the air from that part of the Indian Ocean which lies to the north of Madagascar, and an eastern wind would blow there towards tropical Africa. But the fact is, the south-west monsoon blows in that part, which is from the heated land, and not towards it.

We have thus traced some effects of condensation of vapour in producing atmospheric currents within and near to the tropics. But the same process may be discovered in active operation beyond the tropics in both hemispheres, extending into the temperate regions, and in one part even into the polar region, giving rise to atmospheric movements of great extent and importance.

One of these winds is the well known south-west wind of the Atlantic Ocean, which passes from the northern tropic about the West Indies, and crosses the Atlantic to the north-western coast of Europe. This wind prevails particularly in the latter half of the year about the British islands, and extends to Norway and Iceland, and into the arctic sea, and throughout its whole course is distinguished for its rain and local winds. Rain and snow fall very freely on the western side of the mountains of Norway, and make the country warm in the winter, compared with contiguous parts in the same latitudes; there must, consequently, be ascending aerial currents and winds. The western parts of Ireland, England, and Scotland, are wet and warm in the winter for the latitude. In Lancashire, at Esthwaite Lodge, 86 inches of rain fell in a year, and at Beddgelert, on the south side of Snowdon, in North Wales, 79 inches fell in 1842. Between Ireland and the United States wind and rain are prevalent, and heavier rains and storms are common in the West India Islands. Indeed, the line of this atmospheric current exhibits all the indications commonly seen in those tropical currents which are highly charged with vapour, and this may, therefore, be

considered a current which has flowed from tropical parts, and which terminates in the regions of condensation about Norway and Spitzbergen.

A current to correspond with this is found in the southern hemisphere, which appears to overflow from nearly the same longitude of the tropics, and, doubtless, through the operation of similar causes, to those which gave birth to the northern Atlantic current. It is found off the southern part of the coast of Brazil, by ships proceeding from Europe to Hindoostan, in about the 20th degree of south latitude. From this part a north-west wind blows across the southern Atlantic, and it passes a little to the south of the Cape of Good Hope. Captain Basil Hall says, in his account of his voyage to Loo Choo—"It is essential to the success of a passage from the Cape of Good Hope to Java, or to any part of India, to run to the southward as far sometimes as 40°, in which parallel the wind blows almost invariably from the westward all round the globe. The requisite quantity of easting is thus easily gained, though at the expense of some discomfort, for the weather is generally tempestuous. This point once accomplished, the ship's head may be turned to the northward, and all sail made to reach the south-east trade. On a knowledge of these particulars the success of eastern navigation essentially depends, and with it, if sailing at a proper time of the year, a fair wind all the way from Madeira to Canton may be obtained."* This west wind, which blows all round the globe, proceeds to Van Dieman's Land and New Zealand. In a recent account of the colonization of the latter place, it is stated that "the entire west side of the island is a monotonous line of coast, and on account of the prevalence of westerly winds, is yet little visited; but in its centre, trending towards the funnel-shaped entrance to Cook's Straits, the high pyramid of Mount Egmont rises like another Peak of Teneriffe, full 10,000 feet above the level of the sea, and serving, conse-

* Captain Basil Hall's Voyage, page 2.

quently, as a conspicuous land mark for ships navigating thitherwards from the west; its bold snow-covered crest ever shrouded in mist." Here then we may, for the present, consider this current to terminate. It passes over the ocean through about 210° of longitude; that is, from 45° west to 165° east, but, unlike the corresponding current in the northern hemisphere, it does not approach the polar region. Both currents, however, flow towards lofty mountains, against which heavy rains fall, and near to which winds and storms are prevalent.

In the great Pacific Ocean there are two aërial currents, similar to those we have just traced; one of them in the northern and the other in the southern hemisphere, and apparently overflowing from the great tropical trade wind of the Pacific. That in the southern Pacific may be traced from the eastern side of the islands of New Zealand across to the continent of America, from 180° to 75° of west longitude. Throughout the whole of this extent there appears to be no land of sufficient magnitude materially to disturb this current, and it, therefore, proceeds in its course until it encounters the western coast of Patagonia and the island of Tierra del Fuego. This part is not much frequented, but we have some accounts of it. Captain Fitzroy says—"Beyond the region of tropical or eastern trade winds an almost continual succession of westerly winds is found to prevail. In these middle latitudes easterly winds sometimes blow, but their amount is not more than one-fifth that of the west throughout the year."* And, when reasoning on the possibility of South America having been peopled from the west, he says—"It is not impossible that vessels should have crossed from New Zealand to South America, running always before the fresh westerly winds so prevalent southward of 38°." As this wind approaches the western coast of the southern extremity of America it assumes a more stormy character; and on this

* Captain Fitzroy, page 652.

coast there seems to be a larger amount of condensation of vapour than in any other part of the world in nearly the same latitude.

Captain Fitzroy says—"The climate of western Patagonia is so disagreeable that the country is almost uninhabitable. *Clouds, wind, and rain are continual in their annoyance.* Perhaps there are not ten days in the year in which rain does not fall, and not thirty in which the wind does not blow strongly; yet the air is mild and the temperature surprisingly uniform throughout the year." And, "From Cape Pillar to Cape Horn the coast of Tierra del Fuego is very irregular and much broken, being in fact composed of an immense number of islands. It is generally bold and free from shoals and banks. The coast varies in height from 800 to 1500 feet above the sea. Further in shore are ranges of mountains always covered with snow, whose height is from 2000 to 4000 feet, and in a few instances about 6000 or 7000 feet."* "Fogs are extremely rare on this coast, but thick rainy weather and strong winds prevail. Westerly winds are prevalent during the greater part of the year. All kinds of shifts and changes are experienced, from north to south by the west, during summer, which would hardly deserve that name were not the days so much longer, and the weather a little warmer. Rain and wind prevail during the long more than the short days." These extracts are sufficient to shew the climate of this region of condensation, wherein vapour brought by the western atmospheric current of the southern Pacific, is condensed.

Such are some of the meteorological peculiarities of this terminus of the great western current of the southern Pacific. The large amount of condensation of vapour must, it is presumed, here produce a partial vacuum in the atmosphere, and an ascending current which draws air not only from the west, but partially from the south; and as, in both directions, the sea is open, the air which arrives from these quarters is

* Captain Fitzroy, vol 2, page 312.

charged with a full portion of vapour, and thus copious condensation is continued and perpetuated.

In the Northern Pacific similar phenomena are to be observed, allowing for the effects of local influences. An aërial current prevails from the Japan Isles to the western coast of North America. Captain Fitzroy, arguing respecting the possibility of America having been peopled from the west, says—"Neither is it at all unlikely, on the contrary it is highly probable, that Chinese or Japanese junks were driven to the Sandwich Isles, perhaps across to the American coast."* And again—"Beyond the region of tropical or trade winds an almost continual succession of westerly winds is found to prevail." From the Japan Isles to New Albion and California the sea is quite open; not a single large island exists to disturb the progress of this western atmospheric current, and it, consequently, proceeds to the American coast.* Along the whole of this coast, from the Isthmus of Panama to say 60° of north latitude, there are lofty mountains generally not far from the sea. Reasoning from the principles here maintained, the result, we shall find, must be, that the vapour brought from the Northern Pacific Ocean will be condensed against or near to the sides of these mountains, and effects will be experienced near to them similar to those which have been traced at the southern extremity of America—rain will fall copiously, the climate will be warm for the latitude in the northern part, and the whole will be windy and frequently stormy.

Captain Basil Hall, in his account of the western coast of America, says—"From June to November every part of the south-west coast of Mexico is liable to hard gales, tornadoes, or heavy squalls—to calms, to constant deluges of rain, and the most dangerous lightning: the coast is so unhealthy at this time, as to be abandoned by the inhabitants." Lewis and Clarke passed a portion of an autumn and winter near the mouth of the Columbia river, say in latitude 47°, and the fol-

* Captain Fitzroy, page 652.

lowing extracts present a specimen of the way in which they speak of the climate:—"Nov. 11. The wind was still high, from the south-west, and drove the waves (in the river) with great fury against the shore; the rain, too, fell in torrents." "Nov. 24. Since our arrival the weather has been very warm, and sometimes disagreeably so." On the 11th December—"The rain continued last night and the whole of the day; several of the men are beginning to suffer from the excessive dampness." On the 21st—"As usual it rained all night, and continued without intermission during the day." Dec. 31st—"As if it were impossible to have twenty-four hours of pleasant weather, the sky last evening clouded, and the rain began and continued through the day."

In Cook's third voyage, vol. 6, when near Cape Flattery, in latitude 48°, we have this remark in March:—"Thus we had pepetually strong west and north-west winds to encounter." And some time afterwards it is said—"After leaving Nootka Sound, in latitude 54°, it was stormy. The climate is infinitely milder than that on the east coast of America, under the same parallel of latitude. The Mercury in the thermometer never, even in the night, fell lower than 42°, and very often in the day it rose to 60°. No such thing as frost was perceived in any of the low grounds; on the contrary, vegetation had made considerable progress, for I met with grass that was already above a foot high." It was in April.

The same kind of weather is experienced further north, in 60° latitude, so that the vapour brought by this western aërial current of the Northern Pacific must be spread along the whole coast, where it is extensively condensed against the western side of the lofty mountains which exist throughout this range, producing those drenching rains that have been described, making the temperature high, and creating ascending aërial currents, strong winds, and furious storms.

In the accounts which have been thus given of a number of

aërial currents, they have been traced to various termini, all of which are areas of condensation of vapour. The trade wind from beyond Madeira was followed to the Andes; to which locality another wind, from the Cape of Good Hope, was also traced. The south wind of Peru was found to cross the Pacific within the tropics, and terminate among the islands of the eastern archipelago, to which part a west wind also blows from the Indian Ocean, making this group of islands the common terminus of two opposite winds. Westerly winds have been shewn to blow about the middle of the tropical regions towards the mountains of Africa, though the general direction of the wind within the tropics has been supposed to be from the East. The south-west monsoon of the Indian Ocean also blows during summer. So far, then, we find that in the tropics there are two east and three west winds, and all five terminate against, or among, mountains. Of the winds that blow from the tropical to cooler latitudes, we have seen that, in the northern hemisphere, one reached Norway and Spitzbergen, another to the Himalaya mountains, and a third to the western coast of North America. And in the southern hemisphere one wind passed from Brazil to New Zealand, and another from New Zealand, across the Pacific, to the western coast of South America. All these termini are known to be localities of great condensation of atmospheric vapour, where the temperature of the air is evidently increased by liberated heat, and where partial vacua must consequently be created, and where it is therefore presumed that ascending currents must be formed, making these localities large natural chimnies, towards which atmospheric air flows or rushes with different velocities, from great though varying distances, but with sufficient force to make them the prevailing winds, overcoming or modifying all minor influences, such as the inequality of surface temperature, and the different rotatory velocities of different latitudes, by the superior energy of condensation of vapour, and making the ascending aërial currents,

in these areas of condensation, the prime causes and active producers of all the great winds that are found on the globe.

Sun-heated Land, and Sea and Land Breezes.

On no one point do meteorological writers, and those who treat on subjects connected with meteorology, more universally agree than on the influence of sun-heated land on the adjoining atmosphere, in causing that atmosphere to flow towards the heated land. The heated surfaces of broad continents are pointed out as the causes of strong and long continued winds; and coasts and islands which have their surfaces heated during the day by the sun's rays, are said, with undoubting confidence, to have that heat communicated to the air resting upon them, which causes the air to rise, and thus admits the cool sea air to flow in by day, producing a sea breeze. And these facts are stated to be observable in many parts of the world, presenting, it is assumed, evidence of the strongest kind to support the opinion that such winds and breezes are caused by the air resting on the heated land being rarefied and raised by the direct influence of the sun's rays.

It is true that regular alternating sea and land breezes are found on coasts of continents and islands in many parts of the world. But, to those who think that they are produced by sun-heated land, it must seem a singular fact, that such breezes should not be found in those parts where the causes which are supposed to produce them exist in the strongest degree. The sun must heat the north-western part of the Sahara, or North African Desert, every day up to a very high temperature, yet no regular sea breeze prevails on this coast. Now, if sun-heated land caused the sea breeze in the way described, how could this be? It is known, also, that the temperature of the land in this part sinks greatly at night, and there is,

consequently, that difference of temperature between day and night which it is presumed always produces the sea and land breezes, but no such breezes are found here. The north-east trade wind, in a gentle form, prevails during a great part of the year off this coast, and the atmosphere is clear. To use the language of Malte Brun—"The earth beneath is scorching—the sky above is on fire," on the desert land, while the trade wind near to it is comparatively cool, and yet there is no sea breeze. It may be said that the trade wind, blowing away from the coast, is sufficiently strong to overcome the tendency of the air to flow from the sea towards the hot desert. That, however, is giving up, in this instance, the theory in question. But we shall see, presently, that the sea and land breezes, where they exist, modify or overpower the general currents of the atmosphere, as on the coasts of Peru and in the islands of the South Sea. But why have we not the daily sea breeze on the more southern part of the coast of this dry African Desert, say in about the latitude of 20°, which part is beyond the influence of the trade wind? In this part no regular sea breeze is ever noticed.

Were it, however, this part of the world alone, where the cause which is said to produce the sea breeze exists in so very strong a degree, and yet where no sea breeze prevails, it might be considered one of those exceptions which are occasionally met with that cannot be accounted for, but which are not held sufficient to overturn a theory, resting on a great number of other cases, presenting evidence in its favour of a conclusive character. But the north-west coast of Africa is only one instance out of a number which might be named. In the neighbourhood of the Arabian Sea land is found which, in our summers, is heated up to a high temperature. The southern part of Arabia is very hot compared with the temperature of the adjoining sea, but does the air flow from that sea towards and over the heated land? It certainly does not. On the contrary, when the summer monsoon is the strongest, and the

land of Arabia the hottest, the wind blows from the west, and, consequently, it blows from the greatly heated land, towards and over the cool sea, or just in the opposite direction to what would be found if the common theory respecting the cause of sea breezes were true. And to the south of Arabia, along the eastern coast of Africa, from Cape Guardafui by the dry desert of Ajan, Zanquebar and Mosambique, extending from ten degrees north to twenty degrees south, there is land so greatly heated as to make it some of the hottest in the world; yet the comparatively cool air of the Indian Ocean does not flow towards this land, but, as on the Arabian coast, the wind blows from the heated land over the cool sea. In Major Harris's account of Abyssinia, recently published, is the following passage:—"Landing at Tagura, a port near the entrance of the Red Sea, the embassy crossed the belt of land which stretches for a breadth of three hundred and fifty miles to the mountains; a desert scorched by an ardent sun, and alive only with moving pillars of sand." A popular compilation describes the winds of this part thus:—"In the Mosambique channel, the south-west monsoon begins in April and continues till November. The north-west then succeeds, and continues till April, but does not extend south of 23° of south latitude." "The north-west and south-west monsoons are weaker and more variable in the Bay of Bengal than in the Gulf of Arabia, where they are more constant as well as more violent. In their progress westward (that is, in their more western part) they gradually range over a wider space; they blow over the whole of that track of sea that lies between Africa and Madagascar from the west, north-west, and south-west."* That is, both monsoons blow from the west along this hot coast, which is from the hot land to the cool sea, in direct opposition to the theory contained in Malte Brun's Geography, and copied into Lizars' Atlas.

But other phenomena, which occur during the prevalence

* Lizars' Atlas, p. 37.

of the south-west monsoon, in another quarter, are, if possible, more decidedly opposed to this theory. If any one part of the broad expanse of the continent of Asia could be heated so as to draw air from the Arabian Sea and the Indian Ocean during the summer, it would be that part which lies between Hindoostan and the Lake of Aral, including the region between the Valley of the Oxus and Persia, and the land of this part, unlike Hindoostan, is not screened from the sun by thick vapours. But what says Burnes respecting the winds of this part? Why, that about the latter end of June, though the thermometer was at 103° in the day—"In this country a steady wind generally blows from the north."* And on the 23rd August, after having passed the Oxus—"The heat of the sand rose to 150°, and that of the atmosphere exceeded 100°, but the wind blew steadily, nor do I believe that it would be possible to traverse this track in summer if it ceased to blow. The steady manner in which it comes from one direction is remarkable in this inland country." Again—"The air itself was not disturbed but by the usual north wind that blows steadily in this desert." And he has many other similar passages. Now, the theory to which we have adverted teaches that the heated air over this land ascended, and allowed the comparatively cool air from the Indian Ocean to rush in to supply its place, and thus to constitute the south-west monsoon. But we see that so far from the south-west monsoon blowing into these heated parts, an opposite wind, namely, the north, blew from them towards the parts where the monsoon was then raging, the mountains being, apparently, the common terminus of both.

The belief in the effects of sun-heated land on air, in producing winds, is likely to exercise influence on the conduct of navigators, and may lead them into serious errors. Captain Basil Hall, when giving an account of navigating a part of the Pacific, which is subjected to similar influences to those which

* Burnes, p. 18.

produce the south-west monsoon, has these remarks:—"That portion of the Pacific Ocean which stretches from the Isthmus of Panama to the peninsula of California, lies between eight and twenty-two degrees of north latitude. Now the sun's rays strike directly upon the adjacent great territory of Mexico, and, by heating the land violently, cause the air to rise over it. But the vacuum is filled up, not only from the northward, but by the comparatively cold air in the equatorial regions, in the neighbourhood." And he goes on to say—"When I was sent to visit the south-west coast of Mexico alluded to, and was left to my own choice, as to the manner of performing the voyage, I miscalculated the probable effect of so vast a heater as Mexico, and expected to find the winds from east or north-east, and therefore began my voyage at Panama. I soon learned, however, to my cost, that instead of being to windward of my port, I was dead to leeward of it, and I had to beat against a westerly wind for many weeks."

This part of Mexico has been already alluded to, but it may be desirable again to refer to accounts of it. Humboldt says that along this coast—"Sugar, cotton, cocoa, and indigo, are abundantly produced only at an elevation of from 1968 to 2625 feet." And this is the region of heavy rains and malaria. He further states that—"On the declivities, at the elevation of 3937 or 4921 feet, there prevails a mild climate, never varying more than four or five degrees. To this region, of which the mean annual temperature is from 68° to 69° 8′, the natives give the name of 'Tierras templados.' Unfortunately these tracts are covered with thick fogs, as they occupy the heights to which the clouds usually ascend above the level of the sea." "The plains, which are elevated more than 7218 feet above that level, and of which the mean temperature is under 62° 6′, are named 'Tierras frias.'" Thus it appears that the lower part of this country is very rainy, the middle land is covered with thick fogs, and the

upper is cool from its elevation; consequently, the general surface of the ground cannot be made hot by the rays of the sun striking on it. Occasionally parts may be made hot by the direct rays of the sun, but the general character of the country is that which is given by Humboldt. The heat which produced the winds that surprised and baffled Captain Hall, came, there is no doubt, from the condensation of that vapour with which the atmosphere in this part is known to be loaded, and not from the direct action of the sun's rays on the surface of the earth. And it is very desirable that persons similarly circumstanced with the Captain, should understand the theory of those operations that are going on around them, and which exercise such an influence over them. Captain Hall regrets that he had not previously considered what a great heater the land of Mexico must be, in order that he might have avoided the winds which blow in that quarter. And with his theory in his mind, whenever he approached a land greatly heated by the sun's rays, he would naturally take the requisite means to avoid the wind which he would expect to be blowing on it. Had he, for instance, been afterwards sent with his ship to serve off the north-west coast of Africa, in the summer, and had expected to find a strong wind blowing towards the land because the adjoining desert was a great heater, he would, as has been shewn, have been as much disappointed off the coast of Africa as he was off the coast of America. The surface of the land in Africa is really a great heater, yet there are no strong or long-continued winds found on the coast, as there are on the west coasts of Mexico and Hindoostan. Navigators seldom visit the African coast named, but they pass at no great distance from it, and were there strong winds blowing, would assuredly speak of them. Darwin says—"At St. Jago, Cape de Verd islands, the atmosphere is generally very hazy; this appears due to an impalpable dust which is constantly falling, even on vessels far out at sea. Afterwards, when the air was clear, the hygrometer gave a difference of 29° 6′ between

the temperature of the air and the dew-point." Indeed, from Madeira, by the Canary Islands, along the desert coast to Cape Blanco, and the Cape de Verd islands, either calms or dry winds from the desert are generally met with. The harmattan, or land wind of the desert, is sometimes encountered, and it is this wind which takes the fine dust so far out to sea. The whole of the coast is remarkable for the want of water, in that particular resembling the south coast of Arabia, and the eastern coast of tropical Africa, and in none of those parts does the wind blow from the cool sea to the heated land.

Eastern Patagonia lies between say 40° and 53° south, and the nature of the country may be seen from the following extracts from Captain Fitzroy's Voyages:—"Fresh water is seldom found in these wastes; salinas are numerous. The climate is delightful to the bodily sensations, but for the productions of the earth it is almost as bad as any, except that of the Arabian or African deserts. Rain is seldom known during the three quarters of the year, and even in the three winter months, when it may be expected, but little falls, except on rare occasions, when it comes down heavily for two or three days. Sea winds sometimes bring small misty rain for a few hours, at any time of the year, but not enough to do good to vegetable productions. Generally, a bright sunny day is succeeded by a cloudless and extremely clear night. In summer the heat is scorching, but not sultry."*

This part of America is considerably beyond the tropics, and therefore the land is not likely to be heated up to so high a degree as the dry deserts of Africa or Arabia, yet it is stated to be greatly heated, but no mention is made of regular sea winds blowing towards it. Not only, therefore, is the theory to which objections are here advanced unsupported by facts, but the numerous facts to be met with all tend to

* Captain Fitzroy's Voyages, p. 339.

prove the opposite of the theory; that is, they tend to shew that strong winds blow towards lands drenched with rain and screened with clouds, and that they do not blow towards land strongly heated by the direct rays of the sun.

This theory, so opposed by facts, would probably never have been countenanced, had it not been apparently supported by those movements in the atmosphere, which take place in many parts of the world, called "sea and land breezes." Of these Professor Forbes speaks thus, in his Report to the British Association, published so recently as 1840:—"Land and sea breezes, in all climates, especially between the tropics, are attributable to the more or less heat-absorbing character of the surface of the solid or fluid, in varying the distribution of temperature during twenty-four hours."* These breezes, certainly, often blow towards the land when the sun has heated it during the day, and flow back at night when the land is cooled. And it being concluded, from these observed facts, that each day the sun heated the land, caused the air over it to ascend, and admitted cool air to flow in below, it seemed to follow that where extensive lands were greatly heated by the sun, cool air must necessarily flow in from adjoining parts.

But what really causes those sea breezes that, in so many parts of the world, are known to blow daily from the sea to the land, as soon as the sun has sufficiently exerted his power? Can any other circumstance than the direct influence of the sun's rays on the earth produce that regular daily wind called the sea breeze? Let us proceed to inquire.

The western part of Peru is one of those localities in which regular day and night, or sea and land breezes, prevail; and it is commonly referred to as a place where the sun, by heating the land during the day, causes the sea breeze to blow. It is, therefore, desirable that we should inquire what are the peculiarities of this coast which are likely to affect

* See page 102 of the Report.

the winds daily. Captain Fitzroy, when in Peru, at Point Jara, latitude 23° south, writes thus:—"The tops of the hills on the coast of Peru are frequently covered with heavy clouds. The prevailing winds are from south-south-east to south-west, seldom stronger than a fresh breeze, and often very slight. Sometimes during the summer, for three or four successive days, there is not a breath of wind, the sky is beautifully clear, with a nearly vertical sun. On the days that the sea breeze sets in it generally commences about ten in the morning, then light and variable, but gradually increasing till one or two in the afternoon. From that time a steady breeze prevails till near sun-set, when it begins to die away, and soon after the sun is down there is a calm. About eight or nine in the evening light winds come off the land, and continue till sun-rise, when it again becomes calm until the sea breeze sets in as before." This appears to be a clear description of the sea and land breezes which prevail off this part of Peru; and, lightly read, certainly seems to lead to the conclusion that the sea breeze is caused by the sun heating the land in the way generally supposed. But a fact is stated in this account, namely, that—"Sometimes during the summer, for three or four successive days, there is not a breath of wind, the sky is beautifully clear, with a nearly vertical sun." Such weather as this is described as an exception to the general weather that is found off this coast, and at the time of this exception no sea breeze blew—as it is said that there was "not a breath of wind." Well, what was the state of the land when the sea breeze thus ceased for three or four days? We ought, on the common hypothesis by which sea breezes are accounted for, to expect that the sun, from some cause, ceased to heat the land, and therefore heated air ceased to rise, and cool sea air ceased to blow in from the sea to the land. But we are told by the same writer that, during these four days, "the sky was beautifully clear, with a nearly vertical sun." That is, we are informed by this careful observer, that

at the time when a nearly vertical sun was shining on the land, and the sky was beautifully clear, and when, according to the common theory of the cause of sea breezes, we ought to have had such a breeze of the strongest character, there was "not a breath of wind." The coast of Peru, it appears, was, during these four days, in a similar state to that in which the heated deserts of Africa, and other parts already alluded to, are found when, notwithstanding the great heat of the land, no sea breezes were produced.

But at other times sea breezes do blow on this coast, and it therefore becomes our business to inquire what are the additional circumstances to be observed in this same part when sea breezes blow, that we may be enabled to account for them. If an observer, after having experienced four days of calm weather, with a clear sky, would have noticed what alteration took place in the sky at the time that the sea breeze began to blow, it is very likely that the cause of the sea breeze might have been discovered, and rendered evident. I have not, however, met with any statement of that kind, and must therefore be content to use such information as can be obtained.

When Captain Fitzroy says that during the calm days the sky is beautifully clear, he leaves us at liberty to infer that when the sea breeze blew the sky was not beautifully clear. We are at liberty to draw that inference because he does not speak of the sky being beautifully clear at other times, but seems to limit his statement respecting the clear sky to the calm days. He however more than once states, that during the summer, "the tops of the hills on the coast of Peru are frequently covered with mist." And in another part of his book, when speaking of an adjoining portion of this coast, evidently affected by similar influences, the Captain states some facts which may enable us to understand what is the real nature of the meteorological changes which are taking place in this part of the world that produce the sea breeze.

He says—"In Northern Chili, just before sun-rise is generally the best time for enjoying an unclouded view of the Andes; for scarcely have the sun's beams shot between their highest pinnacles into the westward valleys when clouds of vapour rise from every quarter, and during the rest of the day, with few exceptions, obscure the distant heights."* Now if what has been advanced in a former part of this work is correct, namely, that a cloud, when raised by the warming influence of the sun, has the vapour which it contains condensed into rain, and that thus an ascending aërial current is produced, into which adjoining air will flow, may not the clouds of vapour which rose, as described by Captain Fitzroy, in Northern Chili, generally form cumuli against the sides of the Andes, produce ascending aërial currents there, and cause a flow of air from the sea to supply the place of that which had ascended, and thus create a sea breeze? Not only may this take place, but, from a consideration of the various facts named, we are authorized to assert that it must occur. The existence of the mist, which rose from every quarter in the morning, proved that the dew-point and the temperature were in the part nearly the same.† When the sun heated the lowest stratum of air, the air expanded and rose, taking the vapour intermingled with it to a higher region. As this moist air rose, and became subjected to less pressure from air resting upon it, it would cool, and in cooling condense some of its vapour. Now if the causes in operation were only just sufficient to produce a small thin cloud during the day against the sides of the mountains, that cloud would merely obscure them to the view, and the day might be calm and the sky clear over the low land of the coast. But if the condensation was sufficient to cause rain to fall among the mountains, and air to

* Captain Fitzroy, p. 431.

† "In the evening of the 12th June," says Basil Hall, "the land wind was just sufficient to fill the sails, dripping wet with the heavy dew."—Near Lima, in 18° south.

ascend, other air would be drawn, not from the east, because there lofty mountains intervene, but from over the sea, to supply its place—and thus a sea breeze would blow. And if the dew-point should be high, and the condensation consequently great, the cloud might extend from the mountains and cover the adjoining land and some of the sea, whilst a strong sea breeze might be blowing at a considerable distance from the land.

Darwin says—"During the winter months, both in Northern Chili and Peru, a uniform stratum of clouds hangs at no great height over the Pacific. When on the mountains, we had a very striking view of the great white and brilliant fields which sent arms up the valleys."* These clouds might, in the winter, be so raised as to produce a daily sea breeze of greater or less strength. Smith, in his account of Peru, says—"In Lima, in February, the thermometer, if placed on the open and flat-roofed house-top of mud plaster, rarely ascends above 112°, and at this season the canopy over head is curtained with light clouds, that happily protect the city from the too scorching beams of a tropical sun;"† and when speaking of the northern maritime province, he says—"When the wind descends during the night from the adjoining near mountains, the transition of the temperature is rapid to severe cold." That such clouds, and the air charged with vapour with which they are intermingled, are generally raised daily by the sun, may be asserted from a knowledge of the causes that are in operation. And an observer, alive to the subject, would be as capable, there is no doubt, of tracing them, as an individual on the flat shore of Lancashire can trace the rise of the morning mist, from the Irish Sea, to a considerable height, where it forms a cumulous cloud, and falls in rain, or dissolves in the evening, according as the amount of condensation is great or small. And, admitting that air, with abundance of vapour, is thus raised, and that condensation takes place over Peru, it will

* Darwin, p. 427. † Smith, vol. i. p. 6.

follow that other air from the west must flow to supply the place of that which has ascended, and a sea breeze must blow. This breeze ceasing at night, is a consequeuce of the sun no longer raising the lower part of the atmosphere. When the causes in operation are sufficiently powerful to produce copious condensation on such a coast as that of Peru or Chili, much rain falls, and the sea wind is constant, or blows by night as well as by day, as it does on the coast of Tierra del Fuego. But when the action of the sun on the surface of the land is necessary to heat the air immediately adjoining the land, so as to raise the air, and thus produce condensation—as soon as that action ceases the ascending current ceases, and with it the sea breeze which constituted its supply.

We are then warranted in coming to the conclusion that there are no sea breezes on the western coast of Northern Africa, and other parts that have been named which are similarly circumstanced, although the sun is sufficiently powerful in those places to heat the lower air and make it rise, because there is not sufficient vapour in the air to allow condensation to take place to that extent which shall produce an adequate ascending current. It being condensation that gives power to the ascending current, where that is absent the current is so feeble as to be scarcely felt, or in any way traced, though it may be evident that some portion of the lower air does rise. It may be that there are small ascending and descending columns of warm and cool air in the same locality, producing that tremulous motion which has been often observed, and acting in such a way as not materially to disturb the adjoining region over the cool sea, and, therefore, no sea breeze is experienced. But when there is sufficient vapour to produce an ascending current, then the current may, and probably does, become an ascending mass, extending over a considerable space, without having any small decending streams within it. And the supply of air that is required to restore the equilibrium of atmospheric pressure must come from an

adjoining lower region, and that region being the sea, a sea breeze is formed.

That condensation, to a considerable extent, does take place along the west side of the Andes, in Peru, at the time which seems requisite for the creation of the sea breeze, is known. Smith, who visited the interior of the country, states that—"During the dry season on the coast the rains are experienced in the interior of the country, and lofty range of the high land, especially in the months of January, February, and March, when the rain that falls inland is often very heavy, and on the most elevated regions it is not unfrequently alternated with snow and hail. Thus the dry season of the coast is the wet in the Tierra, or mountains."*

Although but little rain falls on the low grounds of Peru near the sea, it appears, from facts given, that the dew-point must be tolerably high in the northern part. But as the southern wind, that prevails in this quarter, proceeds towards the equator, it has its temperature progressively increased, and will, therefore, not be inclined to condense vapour, unless some material disturbing cause should interfere. This wind blows along the low land of Peru, and over the adjoining sea, and seems to be disturbed only by the daily action of the sun, which, by raising the lower part, commences condensation. At that part of the coast where there is the least vapour in the air, and the greatest difference between the dew-point and the temperature, there will be the least condensation by the daily raising of the lower air, and the least sea breeze. As the general wind advances towards the equator, it takes up more vapour by evaporation, the dew-point rises, and any adequate disturbing cause which may then come into operation, will produce a larger amount of condensation and a brisker sea breeze. And along the whole coast the strength of the sea breeze will be proportioned to the extent of the condensation that takes place over the land. This accounts

* Smith, vol. i. p. 11.

for what we are told by Captain Fitzroy, who says that— "To the northward of Callao the winds are more to be depended on, the sea breeze sets in with greater regularity and fresher than on the southern parts, and near the limits of the Peruvian territory a double-reefed topsail breeze is not uncommon."

The causes which produce sea breezes along this coast are in full operation at Panama. The Hon. P. S. Scarlett, in his book on South America, says, when speaking of Panama— "May 17. It pours with rain five or six hours in the day, and the thunder and lightning are awful. The rain generally begins at eleven o'clock."* Here we see that rain falls about the time that the sea breeze sets in strongly along this coast, and if no condensation was going on in this part but that which produced this rain, it must have produced a strong sea breeze. Further to the north of the line, along this coast, we learn that similar winds blow.

We have seen that no regular daily sea breeze existed along the western coast of the Sahara, or North African desert, although the land is there very hot—yet to the south of that desert a sea breeze prevails. Lieutenant-Colonel Sabine says, when speaking of Sierra Leone—"About ten or eleven the sea breeze commences, usually in the north-west, freshening and becoming more westerly as the day advances." "Towards the evening the sea breeze dies away, and the land wind gradually springs up."† Thus, in that quarter of the world we find that there is no daily sea breeze near to the hot desert, whilst there is one at Sierra Leone. But the country about Sierra Leone is mountainous, and, as the dew-point is commonly high, condensation may, and it is to be presumed that it does, take place daily among the mountains, as we have seen it does among the mountains of South America.

Sea and land breezes are found in islands as well as on the

* Hon. P. S. Scarlett, vol. ii. p. 212.

† Daniell's Meteorology, p. 318.

shores of continents. In the seventh volume of Captain Cook's Voyages it is stated that, when at the Sandwich Islands—"In the harbour of Karakakooa we had a constant land and see breeze every day and night." And the accompanying circumstances attending these breezes are given as follows:—"We generally saw clouds collecting round the tops of the hills, and producing rain to leeward, but after they are separated from the land by the wind, they disperse and are lost, and others succeed in their place. This happened daily at Owhyhee, the mountainous parts being generally enveloped in clouds, successive showers falling in the inland country, with fine weather and a clear sky at the sea shore."*

Malte Brun, who collected information with great diligence, says generally of these islands—"The South Sea Islands, notwithstanding their small circumference, in this manner, as in a sea breeze, during the day time attract the general east wind, which is thus made to embrace them, as it were, on every side, and to blow from all points of the compass towards the central summit of the island. When night arrives the air flows back again, from the summit towards the sea, in every direction."† The lofty summits of the mountainous islands of the Pacific are known to be cool, and they are seen covered with clouds, which must, to a considerable extent, obstruct the sun's rays—how then can they be sufficiently heated, by the direct rays of the sun, to produce the sea breeze that blows during the day? Only one conclusion seems left, which is, that if the sun has acted, it was merely as an intermediate agent, and displayed sufficient power to cause condensation to commence, and that that condensation produced an ascending current and a sea breeze.

If this conclusion be erroneous, it may be easily shewn to be so, as, according to the theory here advanced, the sea

* Captain Cook's Voyages, p. 108.

† Malte Brun, vol. i. p. 385.

breeze must be always accompanied by the formation of cloud. And if it can be shewn that regular intermitting or true sea breezes exist without any cloud having been formed, it will go far towards shewing that the theory is fallacious. It is not for one who has had to collect his information principally from books to say that no such instances can be pointed out, as that would be an assertion of a negative, not founded on information but opinion, and such an assertion would, therefore, be improper. But it appears, from numerous accounts of these phenomena, that sea breezes are always accompanied by an atmosphere pretty fully charged with aqueous vapour; and the breezes are the strongest where the charge of vapour is of a certain height. It is within the tropics, whether on the coasts of continents or islands, where the dew-point is high, that sea breezes principally prevail. And beyond the tropics, where they are found, a high dew-point for the locality exists. Malte Brun says they prevail on the coast of Norway, and there seems to be a higher dew-point about that coast than in any other northern part in nearly the same parallel of latitude. Tropical vapour is carried to the coast of Norway, and if, during the summer, the sun, in the day, can raise the lower part of the atmosphere so much as to commence condensation, a day cloud and sea breeze may be produced in the part. But if daily sun-heated land were the sole cause of the sea breeze, should we find it only in Norway, in a high northern latitude? That country is known to be generally screened by clouds in the day time during the summer, compared with the coasts immediately south of it, and, therefore, cannot have its land heated in a superior degree by the direct rays of the sun; and yet regular sea and land breezes are not felt in the European countries south of Norway. The north-west part of France is heated by the sun during the day, and it cools down to a rather low temperature at night, and yet, when no day clouds are formed, regular alternating sea and land breezes are never

In the *Colonial Magazine*, in an account of the island of Martinique, we have the following statement respecting it:—"The heat is moderated every day by two regular breezes, one, which lasts from the rising to the setting of the sun, called the sea breeze—the other, which begins at seven in the evening, and blows during the greater part of the night, is called the land breeze. The humidity of the atmosphere is excessive. In the course of three successive years the hygrometer of Saussure has given, as the two opposite extremes, 100—60, and for the mean term of the humidity of the atmosphere of the isle, 87—7."* It is very likely that the clouds and rain which produced the regular sea breezes might have been seen in Martinique as they were in Owhyhee, and the connection between them might have been exhibited more palpably, but no accounts of the kind are given.

That clouds form over flat islands, when circumstances are favourable, seems very probable. Captain Fitzroy, in the plates contained in his book, represents them as suspended over the low lagoon islands of the dangerous archipelago; and he speaks of the singular interruptions to the trade wind that occur in these islands. He says—"Not only does the eastern wind often fail among them, but heavy squalls come from the opposite direction." "This is especially the case from November to March." This is the time when evaporation has the most fully saturated the atmosphere with vapour, when the dew-point will, consequently, be high, and condensation the most likely to commence upon any partial heating of the lower stratum of air taking place.

But winds of the nature of daily sea breezes are not confined to the shores of either continents or islands. In the interior of Northern Africa, the great Desert of Sahara is bounded to the south by a mountainous country, and in the flat country, near to the mountains, daily winds are found to blow, as they do in other parts on sea coasts. Denham says,

* Colonial Magazine, p. 316.

in vol. 1, that—"The cool winds (in Bornou), which had prevailed for the last fifteen days, had so purified the air that disease appeared to be taking its departure, and a season of health about to succeed in its turn. These long wished for breezes generally came on about ten in the forenoon, and continued until two hours after midday." Doubtless the morning sun raised the air sufficiently to produce condensation and create an ascending current, which took place among the mountains, when a daily wind from the hot plain blew towards the mountains to supply the place of the raised air, producing a daily breeze in a part very remote from the sea, but which came from the hot land to the comparatively cool mountains.

From the foregoing facts and reasoning we are, it is conceived, justified in inferring that daily sea breezes are not consequences of air, heated by the surface of land, rising, and admitting other and cooler air from the sea to flow into the comparative vacuum thus made, but these breezes are results of condensation of atmospheric vapour, which, in each instance, produces an ascending aërial current that causes the flow of the adjoining air into the vacuum. And in the absence of the sun the air, which had been warmed by the condensation of vapour, becomes cool and flows back—thus producing daily alternating sea and land breezes.

Unequal Temperature at Certain Heights in the Atmosphere.

When ascending currents flow against the sides of mountains, condensation taking place during the ascents, it is apparent that the currents will take the heat which is liberated with them to some certain height, and in the

locality produce a temperature higher than generally belongs to the latitude and elevation; and if the cause of the ascending current is of a permanent nature, the general climate of the part will be modified accordingly. An effect of this kind, it is presumed, is produced in the region of great condensation near that part of the tropical Andes already adverted to, although we have no particular account of it. Humboldt, however, mentions a fact which illustrates the point: he says that when they were going over the Pass of Quindihi, 11,499 feet high, and in the latitude of 5° north, rain fell heavily. Now as the rain fell at that height, it must have been previously carried or generated still higher; but in an atmosphere unaffected by particular influences, rain could not be formed at so great a height, and if carried thither, would be converted into hail by the cold which ordinarily exists at that elevation.

But a more striking instance of warmth of climate, at a considerable elevation, being produced by condensation of vapour, is given by Archer, in his travels among the Himalaya mountains. When speaking of a part among these mountains, in about 31° of latitude, he says—"The limits to the cultivation of corn vary, but the maximum elevation is estimated at 13,000 feet, a point which theorists have buried deep under perpetual congelation." According to Leslie, the height of perpetual congelation in this latitude is 11,253 feet. But these theorists were not aware of the influence of condensation in warming parts at great heights. To ripen corn at the elevation named, required not only that the heat should be carried to a great height, but that it should be so constantly taken thither as to enable the crop of corn to grow and reach maturity! Dalton says—"Every habitable latitude enjoys a heat of 60° at least for two months, which heat seems necessary for the growth and maturity of corn;"* and Humboldt says, that in the island of Teneriffe, in 28° north, the highest

* Dalton, p. 124.

point for the growth of wheat is only 1,300 feet, or just one-tenth of the height at which corn grew on the Himalayas.

Daniell gives some facts respecting vapour at considerable elevations. He says that Mr. Green, when in a balloon—"At an elevation of about 9,890 feet, found the dew-point at 64°, exactly the same as I ascertained it to be at the surface of the earth. At 11,060 feet it had fallen to 32°." Colonel Sabine found that—"At Sierra Leone, the dew-point of the vapour at the level of the sea was 70°, and it was the same, at the same hour, upon the summit of the Sugar-loaf Mountain, 2,520 feet above." "At Trinidad, the temperature of the air at the level of the sea was 82°, and the dew-point 77°; 1,060 feet above they were both 76° 5′, and precipitation was going on." "At Jamaica, by the sea side, the temperature of the air was 80°, and the point of deposition 73°, while on the mountains, at the height of 4,080 feet, they were both 68° 5′. At a station not five hundred feet higher, by experiment twice repeated, the point of deposition was found to be 49°, and the temperature of the air 65°."* In all these cases vapour had, doubtless, ascended and formed cloud, and the liberated heat kept up the temperature. Daniell gives also the following from De Luc's observation on a mountain:—"Pendant que je réfléchissois sur l'apparition subite des nuages, je découvris un petit amas de vapeurs, du côté de nord, à 3 ou 400 pieds audessous de moi: Je le considérois avec attention, et je remarquois d'abord que son volume augmentoit sensiblement, sans qu'il me fût possible d'appercevoir d'où lui venoient ses accroissements. Je vis ensuite qu'au lieu de s'abaisser à mesure qu'il grossissoit, et qu'il paroissoit même devenir plus dense, il s'élevoit au contraire. Le vent le poussoit vers moi. *Il m'atteignit enfin, et m'environna tellement* que je ne vis plus ni le ciel ni la plaine. Je pensai au même instant, à *observer mon thermomètre qui étoit suspendu* en plein air, exposé au soleil et que j'avois vu auparavant à 42°. Je

* Daniell's Essays, p. 119.

présumois que l'action du soleil étant interceptée par ce nuage mon thermomètre devoit baisser et je fus très surpris de la voir au contraire à 45°. Le nuage, qui continuoit à monter obliquement vers le sud, abandonna bientôt le lieu où j'étois, le soleil reparut, mais, malgré son action, le thermomètre rédéscendit."* The higher temperature was, doubtless, produced by condensation, and that gave the buoyancy which caused the ascent of the cloud. It is rather surprising that facts like these did not lead inquirers into the right path of discovery.

It is sometimes said that contiguity to the sea causes coasts to be wet and warm, but this does not accord with numerous facts. The island of Newfoundland is in latitudes from 47° to 50° north, the same as the middle of Continental France, yet the former place is thus described in a popular geography:— "In winter the cold is excessive, nothing but snow and ice being seen, and the bays and harbours being entirely frozen." And in Quebec, in the latitude of 47°, the temperature sinks to 32° below zero! in the winter. The coast of Labrador is in say between 50° and 60° of latitude, but the cold of winter is intense compared with that of the British Isles and Norway. And, according to Perouse and others, there is as great a difference, in the same latitudes, in parts equally near the sea on the east coast of Asia and the west coast of America. These differences all result from the eastern coasts not being warmed, as the western are, by the condensation of vapour against elevated land. Yakutz, in Siberia, is said to be the coldest part on the continent of Asia, having sometimes a temperature of 90° below freezing; this place is 130° east of London, and of course the same distance from the Atlantic Ocean. But at Fort Reliance, on the great Slave Lake, about the same latitude, in North America, Captain Back found a temperature of 102° below freezing, yet that place is only about 30 degrees from the coast of the Pacific;

* De Luc, tom. iii. p. 251.

it, consequently, is 100° of longitude nearer to the ocean on its west side than is Yakutz. But in America the vapour from warmer latitudes had been more decidedly intercepted and condensed, by mountains, than it had been in Asia. It is the high ridge of the rocky mountains that forms the barrier between the warm climate of the western coast of America and the intensely cold one of the eastern parts. Such a complete barrier does not exist in Asia, the northern part of which is, to some extent, warmed by the vapour from the Atlantic.

The Connection of Atmospheric Currents.

The various atmospheric currents which we have passed under view have been treated as separate currents—but it is not to be supposed that they should be considered as absolutely separated from each other. The probability is that every such current is disposed to move forward and form a fresh current, and thus produce a general circulation of the atmosphere. But those which have been distinguished by separate names, have been so far modified by local influences, as to give each of them, in the lower region of the atmosphere, a particular direction and character, and they have been treated separately, as lower currents, in order to show their connection with the local influences. Yet in some of them the marks of separation are not very palpable, and on further inquiry it may be found that what we have treated as two currents may be only one. Captain Basil Hall says that in the southern hemisphere, in the latitude of about 40°, a west wind blows all round the globe. And it may be that the islands of Van Diemen's Land and New Zealand merely lie in the path of this wind, and do not separate it into two currents. This, however, would only oblige us to say that

the current which left the tropical region in Brazil proceeded to the parts named, and forward across the Southern Pacific Ocean to America, as one current, instead of speaking of one terminating at New Zealand and another at America. And it possibly may be that some connection may exist between the western wind that blows on Cape Horn, and that which crosses the Southern Indian Ocean to New Zealand, but the facts given by voyagers afford less countenance to this supposition than to the former one. A moderate south-east wind appears to blow near the eastern coast of Patagonia, which would cross the path that would have to be traversed by a westerly wind passing from Cape Horn to join that which crosses the Southern Indian Ocean. In the present state of our knowledge, then, this appears to be a break in the general west wind, which Captain B. Hall says blows all round the globe in the latitude of about 40° south; and the break appears to be attributable to the great condensation of vapour in the neighbourhood of Cape Horn. In the northern hemisphere more disturbing influences exist than in the southern. The mountains of the British Islands and Norway seem to draw on the Atlantic return current, and cause it to terminate about Norway, although a part of it evidently proceeds farther on to the icy sea. The south-west monsoon of the Indian Ocean terminates principally against the lofty ridge of the Himalaya mountains, but it is not unlikely that a part of this wind proceeds over the China Sea northward as far as the Japan Isles, and then turns westward across the Pacific to the American coast, along which we have seen it spreads, though it does not pass the mountain-ridge, which runs nearly parallel with the coast. It may then be that the Japan Isles, at certain times, have sufficient power, arising from the condensation which takes place over or near to them, to divert or bend, or partially to arrest the western return current that is disposed to pass near to or over them, without being able entirely to absorb and thus terminate it, as a lower current in their

locality, as the more lofty Himalaya and American mountains do in their particular districts.

Captain Basil Hall, in a letter to Mr. Daniell, inserted in his Essays, when speaking of the North Atlantic eastern trade wind, has this passage:—"As the ship advances to the southward, she finds the trade wind drawing round gradually from east to north-east, and finally to north-north-east, and even north at the southern verge of the north-east trade." And he afterwards states that, on first meeting the eastern trade of the South Atlantic, it "does not blow from the east, as the navigator is led to expect, or in a direction parallel to the equator, which would be to him a fair wind, but it meets him, as it is emphatically termed, smack in the teeth." And, subsequently, the captain attempts to account for these north and south winds near the equator in this way. He says, speaking of the north-east trade—"As this cool air, however, is drawn nearer to the equator, and comes successively in contact with parallels of latitude moving faster and faster, this constant action of the earth's rapid easterly motion gradually imparts to the superincumbent air the rotatory velocity due to the equatorial regions which it has now reached; that is to say, there will be less and less difference at every moment beween the easterly motion of the earth and the easterly motion of the air in question; while, at the same time, the other motion of the same air, or that which has a tendency to carry it straight to the equator, having been exposed merely to the friction along the surface without meeting any such powerful counteracting influence as the earth's rotation, will remain nearly unchecked in its velocity. Thus, as I conceive, the trade wind must gradually lose the eastern character which it had on first quitting the temperate for the tropical region, in consequence of its acquiring more and more that of the rotatory motion of the earth, due to the equatorial regions it has now reached."* If the influence here pointed out were

* Daniell's Essays, p. 462.

the cause of the east wind ceasing to be such, and becoming north and south winds in the Atlantic, the same phenomena would occur, in a more palpable manner, in the Pacific Ocean, seeing that the eastern wind of that ocean has a much greater range of longitude in which it may acquire the full rotatory velocity of the earth; and it would, therefore, more decidedly lose its eastern character. But the east wind of the Pacific blows steadily over the whole extent of that ocean. Condensation, on the opposite continents of Africa and America, probably affects the Atlantic atmosphere so as to produce the peculiarity described by Captain Hall.

Among the various currents of which we have treated it has been found that some moved parallel, or nearly parallel, to each other, but in opposite, or nearly opposite directions—this is most palpably the case in the wide and open range of the Pacific Ocean. The eastern trade wind appears, at times, to extend from tropic to tropic, aud the western return currents are said to touch on the 40th degree of latitude in each hemisphere. But the limits of these currents may, from the causes known to be in operation, be presumed to vary with the seasons. In the summer of the southern hemisphere there will be more vapour formed and condensed on the south side of the equator, and in the summer of the northern hemisphere on the northern side, and the western return current will, in each hemisphere, no doubt, extend its limits at that period when it is furnished with the greatest power. The islands which lie in the path of the eastern trade wind will, also, have their disturbing and modifying influences, according as condensation takes place more or less freely among them. But notwithstanding all these disturbing causes, it appears that, between the ordinary, though varying, limits of the eastern trade wind and each of the western currents, there is a space in which neither wind decidedly prevails. This line or stripe may, with reference to our present subject of inquiry, be considered as belonging to the region of calms; not because it is absolutely calm, but because neither the

one nor the other of the adjoining great atmospheric currents predominates in it. This stripe is, by navigators, represented to be generally cloudy or misty, and to have not unfrequently rains and varying winds, weather that might be supposed likely to prevail from the causes that are known to be in active operation in the neighbouring parallels. Such a region of calms is said to exist about each tropic in the Pacific Ocean. One is also found in the Atlantic, between the north-east trade wind and the south-west return current. And such an one exists, in tropical parts of the Indian Ocean, between the south-east trade wind and the north-west wind that blows from the Indian Ocean towards the islands of the East Indian archipelago, and is spoken of by Cook. These regions of calms have been avoided by navigators, excepting when they had to cross them, and, consequently, they have seldom given many particulars respecting them.

In addition to these lines of calms there are particular localities which may be considered regions of calms; yet these regions are not, as the name may seem to imply, absolutely calm, but in them no particular wind prevails. Calms are there common, but they are broken in upon by sudden storms, and during these storms the wind blows from any, and sometimes from every point of the compass. One of these regions is in that part of the Atlantic which is within the tropics, and it extends along the coast of Africa. Excepting where west winds blow in the Gulf of Guinea this region has no regular wind: here evaporation goes on until the atmosphere is nearly saturated with vapour, and the neighbourhood of the Gulf of Guinea is known to be one of the most unhealthy, and of the least favourable for navigation, of any region of the globe.*

* "The great difficulty of the outward-bound voyage commences after the ship is deserted by the north-east trade, as she has then to fight across a considerable range of calms, and of what are called the variables." And in the homeward-bound voyage the same writer says—"After reaching three or four degrees of north latitude, the ship will lose the south-east trade, and re-enter the variables." (See Captain B. Hall's Letter in Daniell's Essays, p. 470.)

Another of these regions of calms is found in and near the Gulf of Panama, not far from the equator, and the kind of weather experienced in this part is graphically described by the Hon. P. C. Scarlett. He says, on April 19th—"We are now becalmed, and in the worst part of the world, three degrees north of the line. A heavy oily swell, a gloomy sky, spongy clouds, the ship creaking, sails flapping, and all hands longing for a change. Then the drowsiness caused by this temperature (very hot) is quite overpowering. I am sure a week of probation like this would injure the strongest constitution, such is the debility and loss of energy which it occasions."* These two regions lie near the equator, immediately to the west of the two continents of Africa and America, and these continents intercept the eastern currents which, in other parts, flow along within the tropics. But though there are no regular lower horizontal currents in these parts of the world, we are not to conclude that the same masses of air remain constantly in them: this would be contrary to the general laws which govern the atmosphere, which laws produce motion and change, to a greater or less extent, every where. The air in these regions of calms being pretty fully charged with vapour, and heated by a tropical sun, must have a tendency to rise and expand at some certain height, and a fresh supply must flow in below from surrounding parts, though not with sufficient strength to constitute a wind. And the sudden storms or tornadoes, as they are generally called, which take place in these parts, must be effects of local, rapid, and considerable condensation, and must, therefore, be presumed to produce ascending currents in the particular places, creating irregular and temporary disturbances, both in the upper and the lower regions of the atmosphere.

In these regions of calms the dew-point is generally high, say, between 70° and 80°, and they constitute some of the most unhealthy localities that are known. Indeed, what is

* Hon. P. C. Scarlett, p. 175.

called malaria seems to prevail more or less wherever the dew-point rises above 70°, whether it be over land or sea. And even when it is somewhat lower than 70°, a certain degree of malaria is common, which produces marsh fevers and agues. But when the vapour which gives the high dew-point is condensed, and falls as rain, or a dry wind sets in, the virulence of the malaria is abated, or it entirely ceases. The uniform coincidence of a high dew-point with malaria fever suggests the idea that they may have the relation of cause and effect; and it may be well to consider whether that fever is not produced by a disturbance of evaporation from the lungs.*

Descending Winds.

Ascending aërial currents, produced by condensation of vapour, have been shewn to be important agents in creating and continuing the great horizontal currents of the atmosphere. But the air of these ascending currents is not heaped up in the localities in which they exist. The state of the barometer shews *that, so far from there being more air in the parts where they are found,* there is generally *less, consequently, that* which *ascends must* readily *expand, spread out, and* diffuse itself around. Now it is very desirable that these expansions and spreadings should be traced, and the effects they produce be noted; and though our *knowledge of what takes place in the higher* regions of the atmosphere is very imperfect, yet scattered facts, when brought together, may enable us to obtain some perception *of* what is going on in this obscure department of Nature's works.

It has been already shewn that the theory which teaches

* See a paper printed in the Philosophical Magazine for February, 1839, "On Malaria."

that the heated air of the tropics rises and flows over in the higher regions of the atmosphere, towards the poles, is not universally true. Indeed it appears to be rather the exception than the rule, as the various western currents on the surface of the globe that have been traced, sufficiently prove. The fact, however, that the heated air of the tropics does not universally, nor even generally, return to the poles in the higher regions, has, it is conceived, been sufficiently established. But what are the particular causes which determine that the air which had been heated, and carried to a certain height in the atmosphere, should, in an adjoining part, descend, and become a lower current, as we have found it does? If we suppose that the raised air is heaped upon the adjoining air, it will press into it, and cause it to spread, and this would produce a wider expansion in the middle regions rather than a descent to the lower. The warmed air itself would, however, obviously have a tendency to expand and flow, in the higher regions of the atmosphere, towards the poles; and the cause of its frequent descent to the lower region must be sought in some other operation of nature.

In examining the phenomena attendant on ascending aërial currents, the most striking seems to be the production of rain by the condensation of vapour, the quantity of rain produced being proportioned to the amount of condensation. Over the sea within the tropics, and in some other parts, when the atmosphere is undisturbed by any powerful cause, the rain produced by condensation is small, forming merely a mist, and making the weather cloudy or hazy, and the mist descends to the earth with a slow motion. But where there is sufficient vapour, and an adequate disturbing cause, a powerful ascending current is produced, and more copious rain is the result. The small particles of water first formed in the ascending current will be carried up with the stream of air, and coming in contact with other particles they will unite and form globules, or round drops. And the greater the height to

which the rain is carried, and the more complete the disturbance and turmoil within the current, the larger will be the drops. As we suppose the current to expand in the higher regions, it would carry the rain with it in its expansion, until the force of gravity overcame the carrying or suspending power of the current. The rain would now begin to descend, and as the larger drops would fall with the greatest rapidity, they would strike against and unite with the smaller, until, on approaching the earth with accelerated speed, they would be of a size, and fall with a velocity proportioned to the height from which they had descended, and the thickness of the cloud through which they had passed.* When warm rain falls, it would seem that it must have been not only produced in the interior of an ascending column where the air was warm for the elevation, but it must also have descended through a mass of such air to the earth; whilst any rain which, by the ascending and expanding current, should be violently thrown beyond the range of the warmed current into cold air, would be likely to reach the earth as a cold rain. Where the rain was carried up to a great height and then thrown off to adjoining very cold air, the drops might be frozen, when they would descend in the form of hail. But it would be impossible for myriads of drops of rain or hail to fall in this manner without bringing with them much of the air by which they were surrounded. If this reasoning is correct, it will follow that whenever rain or hail falls from a considerable height in the atmosphere it must bring with it more or less of air from the higher regions. And if the process just described be supposed to continue, there would be a continued descent of air, and the process taking place over a sufficient extent, there would be, in that space, a bringing down of the higher

* "A drop of the twenty-fifth part of an inch, in falling through the air, would only gain a celerity of 11¼ feet, while one of a quarter of an inch would acquire a celerity of 33½ feet."—Leslie.

parts of the atmosphere to the surface of the earth in such a way as to produce palpable local effects on the mass of the atmosphere.

Does not this accord with what is experienced in many places? Sailors say that heavy rain or hail "lays the sea." The fact, no doubt, is, that the descending air counteracts the effect of the horizontal wind which raised the waves. When heavy rain falls suddenly it always brings wind with it. It is common to say that the wind brings the rain, but that form of speaking equally expresses the fact that the two come together. And if what has been advanced respecting the manner in which rain is produced is true, it is only an ascending current of air that can produce heavy rain, and carry that rain up with it. In afterwards descending from a height the gravity of the rain must be the active cause in operation, and that cause produces the effect of which we are speaking, the descent not only of the rain but of the air that was intermingled with it. When partial but heavy showers of rain are seen in profile from a favourable situation, the rain may be often seen descending from the cloud in which it has been produced, and we may infer that the rain carries with it a part of the air which it encounters. And, under such circumstances, the wind in the part is invariably found blowing in the direction indicated by the fall of the rain. Indeed the whole may be witnessed occasionally at sea in one view. From a ship's deck the rain may be seen falling and the wind blowing against the sails of other ships, or carrying smoke in the direction of that fall, although a calm may exist in contiguous parts, or the general wind may be blowing moderately in a different direction. The inference to be drawn from observing such phenomena is, that the rain descended by its gravity and carried the air with it, and the air, when it reached the earth, moved forward in the direction given to it by the rain, until its acquired force was expended.

When a current of air fully charged with vapour reaches such a part as the West India Islands, and is there caused to rise and flow over in the higher regions of the atmosphere towards the pole, the rain which is there formed may, in its *descent, bring air* down to the surface of the earth. And *this operation taking place over a wide space,* the upper aërial current would, in its descent, force away the lower air and occupy its place. The north-east trade wind blows over a part of the West India Islands as well as towards the Andes, and those islands appear to have the power of condensing atmospheric vapour and bringing down rain; and among them the process described may, and probably does, take place, which brings down the air that might otherwise be an upper current, and makes it become a lower current. In the southern part of the Caribbean Sea the dew-point is represented as being as high as 80°, and copious condensation is likely to take place in that part of the world when disturbing causes come into action. The dew-point continues high in the direction of this aërial current, as it moves towards the north-east, yet in the southern part of the United States it is seldom found more than 75°; the current must, therefore, have parted with some of its vapour in the formation of rain. From this part, across the Atlantic to the north-west coast of Europe, rain falls abundantly, and the dew-point is proportionately reduced, until, on reaching the British Islands, it is seldom above 60°. In Norway it is lower, and in both these parts rain falls freely, particularly against or near to the south-west sides of elevated lands, up which the current is forced by its inertia; and these localities are, in the autumn and winter, warmed by the large amount of condensation that is produced from this south-west current. Thus, there will be found along the line named, frequent ascending currents producing rain, and the rain, when formed, bringing down the air with it, keeping the whole atmosphere, in the part, more or less in a state of turmoil and agitation: and

the high lands of the western sides of the British Islands and Norway, by the great condensation which they cause, and the comparative vacua which they produce, whilst they increase the agitation, tend to draw this south-west wind, as a lower current, from the tropical regions towards themselves. In the return current, which proceeds from Brazil to New Zealand, the same peculiarities are observable as those seen in the Northern Atlantic. Captain Fitzroy says, that "at Rio de Janeiro, in summer, thunder storms often occur." "Gales, in the latitude of Santa Martha, generally commence with north-westerly winds, thick cloudy weather, rain, and lightning. The climate is unhealthy in December, January, and February, and during the whole year there is a deal of rain."* From this part of the Brazilian coast the north-west wind blows as far as New Zealand, and it retains its character throughout the whole extent, as it is rainy and much disturbed. We have seen that Captain B. Hall says that getting into this current is advantageous in order to proceed east, but it is "at the expense of some discomfort, for the weather is generally tempestuous." Now, as that is the case, there must be much condensation of vapour, ascending aërial currents, formation of rain, rushing in of air below, and descending wind produced by the fall of rain: in short, all that kind of disturbance which we presume attends the progress of a tropical current, highly charged with vapour, in its passage to a cooler region. In the two return currents of the Pacific Ocean similar disturbing causes exist, and weather of a similar character is found to prevail.

As an ascending aërial current, which reaches a great height, must condense nearly the whole of the vapour intermingled with it, should the mass afterwards descend, the air must descend without the vapour that it previously contained. And should the air in the neighbourhood of a locality where great condensation is taking place be found very dry, it may

* Captain Fitzroy, p. 84.

be inferred that it has had a large part of its vapour condensed by having been carried up to a great height, at which height rain was formed and fell; the air, or a part of it, proceeding on to another part, where it descends as a dry air. This is a point that has been but little noticed by observers, but it has been incidentally mentioned. In King and Fitzroy's Voyages, it is said that, in a part near Cape Horn, of which we have already spoken, where much rain fell, one inch of *water evaporated in twenty-four hours.* Such rapidity of evaporation *is incompatible with a high dew-point at the same* time and place; it may, therefore, be concluded, that at the time of this evaporation the dew-point was low; yet it was in the same district in which it is stated that twelve inches of rain must have fallen in the course of thirty days. This, then, is an instance of a dry atmosphere being found, that is, an atmosphere with but little vapour in it, when all around much rain fell. The dry air, it is evident, could not have come from a considerable distance in the lower region, and we must therefore conclude, that it could only have come from the higher parts of the atmosphere which had been deprived of their vapour by condensation.

To the east of the Andes, near the Caribbean Sea, is a locality in which the dew-point is generally high, sometimes as high as 80°, and in which condensation takes place very freely, as much rain falls; and yet here, in a particular place, Humboldt incidentally states that evaporation goes on rapidly, and there must, consequently, be a low dew-point compared with the temperature. He says that—"At Cumana, the surface of the sea in the port generally ranges from 70.3° to 79.3°; and the temperature of the air, in the season of the floods, is as high as 91°. But at Aroya there are extensive salt works, and evaporation is so rapid that salt is collected in eighteen or twenty days after the reservoirs have been filled." Now the general state of the atmosphere about this part is moist, it being highly charged with vapour brought by the

Atlantic trade winds, and the dry air of Aroya can, therefore, only be presumed to be an overflow from an ascended current that has had its vapour condensed into rain, which brought down the air into this part of the lower region of the atmosphere.

I do not know what was the rate of evaporation at Aroya—Humboldt appears to have thought it extraordinary; but for an inch of water to evaporate in twenty-four hours, as it did near Cape Horn, is surprising, when the low temperature of the part is considered; *at this rate 365 inches of water would* be evaporated in a year.

Although this degree of dryness of the atmosphere may be considered extraordinary, yet dryness, apparently from the same cause, and that, too, of a high degree, is not very uncommon. It is well known that, in many parts of the world, the dew-point is high at one time and at another comparatively low; and, under certain circumstances, the one state quickly follows the other. In the summer or autumn of our own country, when the atmosphere has been for some time stagnant, evaporation has proceeded until a large amount of vapour has passed into the air, and the dew-point has become high, say 65°. But a thunder storm takes place, and the ground is deluged with rain; the storm is soon over, the weather becomes clear and bright, and the air is said to be purified by the storm. But, under such circumstances, what meteorological alterations can be detected in the atmosphere? Why, much of the vapour previously existing in the air has disappeared, and the dew-point has fallen from 65° to 60°, or perhaps to 50°, furnishing evidence, of the most convincing character, that a part of the vapour which had previously existed in the atmosphere, in an aëriform shape, had been, by a sufficiently low temperature, condensed, and converted into rain. The air is now found comparatively dry, and evaporation goes on much more rapidly than it did before the thunder storm. Before the storm the

air rather wetted than dried anything exposed to it, afterwards it dries rapidly, and is in a state approximating to that in which the air near Cape Horn permitted an inch of water to evaporate in twenty-four hours.

In Tierra del Fuego condensation takes place to a great extent, and with as much violence as, if not more than, in any other part of the globe, and it is consequently the most likely place to find a large mass of dry air descending on a neighbouring part; and, accordingly, we find that in Eastern Patagonia the air is very dry.

The western part of Patagonia is another region of copious condensation. From extracts already given, it will have appeared that for heavy rains and fierce storms this part is scarcely surpassed by Tierra del Fuego. It is possible that a part of the air, dried by condensation, about the mountains of Western Patagonia, may cross the Andes, and descend to the eastern plains. But there is another district that is supplied with dry air, which probably comes from this region of condensation. The rain and storms of this coast extend northward to the island of Chiloe, and even to a part of Chili, becoming more moderate in the latter part. But further north, along the whole coast towards the equator, to say about the fifth degree of south latitude, the air is sufficiently dry to prevent any considerable fall of rain on the coast, and through a large extent no rain falls. Yet there is a constant flow of air along this coast from the neighbourhood of the region of condensation and storms just named, though it does not come from the part near the surface of the earth. Now, may not the air from this region of storms overflow to the north, and, descending on the coast between the latitudes of 35° and 30°, flow from thence to the vicinity of the equator? The flow of air is here constantly from the south, and, from facts named, the dew-point must be low in the northern part of Chili. Both the temperature and dew-point appear to rise as the aërial current approaches the equator; until within a

few degrees of the line rains take place. But the great mass of the aërial stream turns to the west, and passes across the Pacific to the Indian Archipelago.

As any one portion of the atmosphere readily acts upon other portions, according to the way in which each is modified by heat and cold, and the motion given to one part is propagated through another until the force is expended, every current will exert a certain force on adjacent parts, and were we acquainted with all that takes place in the great aërial ocean which surrounds the globe, we should be able to trace the separate force of each current, and shew where it had been expended. That part of the continent of South America in which the rivers Amazon and Oronoco take their rise, is a region of great condensation. The atmospheric vapour is supplied from the north-east and south-east trade winds of the Atlantic Ocean, and a part of the atmosphere thus brought, we have supposed to have been turned round and converted into two return currents, which took a portion of the vapour they contained to the west coast of Europe, in the northern, and New Zealand in the southern hemisphere. But still very copious condensation takes place near the Andes. On the Upper Oronoco, near Rio Negro, Humboldt was told that, on account of the rains, the sun and stars were seldom seen, and that it sometimes rained without intermission for four or five months. The water that fell in five hours, on the first of May, he found to be twenty-one lines in height. And the quantity of water here furnished to rivers seems to be greater than in any other part of the globe. We are led, therefore, to presume that there must be an overflow of dry air from this part, as the air which ascends to produce all this condensation must pass somewhere. Yet there does not seem to be that immediate descent of a large quantity of air to the surface which appears to take place near to the southern extremity of America. In Scarlett's account of this part of America it is shewn, that there is reason to believe

that currents prevail in the neighbourhood of this part in the higher regions of the atmosphere, moving both east and west from the Andes. He states that the ashes from the volcano of Cosiquina floated in the air to Jamaica, and at the same time south-westward 1,100 miles; there must, consequently, have been aërial currents to take the ashes to these parts, so decidedly in opposite directions. The current which flowed to Jamaica is known to pass above, aud in an opposite direction to, the north-east trade wind, but to what part did the other upper current proceed? May we not reasonably suppose that it proceeded westward, to feed that great aërial stream which, within the tropics, flows across the Pacific? I know not of any account of dry air descending into the Bay of Panama, yet such may be the case in the western part, or it may reach the surface of the sea farther to the west. An oceanic current moves from the bay to the Galapagos, whilst another comes from the south. Captain Fitzroy says—"On one side of Albemarle Island the temperature of the sea, a foot below the surface, was 80°, but at the other it was less than 60°." And, when speaking of the atmosphere, he says—"How different is the climate of the windward and leeward islands of this group! Here (to windward) we were enveloped by clouds and drizzling fogs. At Tagus Cove and James' Island (on the north side) a hot sun nearly overpowered us, while the south side of Albemarle, Charles, and Chatham Islands was almost always overshadowed by clouds, and had frequent showers of rain." "The southerly trade or perennial wind is very moderate; the winds appear to be much lighter and more variable to leeward of the archipelago, while the current (oceanic) is considerably stronger."* It is not improbable that the upper current, which brought the ashes 1,100 miles from the volcano of Cosiquina, may here reach the surface of the sea as a dry wind, and may form that clear atmosphere which is said to be found in the Pacific imme-

* Captain Fitzroy, p. 498.

diately north and west of the Galapagos. In this, as well as in many other parts, a knowledge of the state of the dew-point would be likely to throw light on the movements of the atmosphere.

Other areas of condensation, such as the East Indian archipelago, the Himalaya mountains, and the west coast of North America, must, we presume, discharge their dried air on neighbouring regions, but with our present information there is no sufficiently palpable evidence to justify an attempt to trace them.

Inequality of surface temperature must be a sufficient cause to produce, in the lower regions of the atmosphere, a slight general flow of air from cold to warm climates; and the general condensation of vapour in the low level regions of the tropics produces a similar result. These two influences are energetic enough to produce a slow general flow of the lower portion of the atmosphere from the polar to the tropical regions, where, from the operation of causes already pointed out, it is inclined to move from east to west. In this eastern movement the air encounters elevated lands, and, by its own inertia, flows up their sloping sides to a height which causes additional condensation to take place in the localities.

The air, moving towards considerable elevations, produces different kinds of weather, according to its temperature and moisture; and an examination of it, at any time, may shew what weather will be produced by it in the locality; as, for instance, suppose the wind in St. George's Channel to change from a dry cloudless north or east to a south-west wind, any person, by ascertaining the dew-point and temperature of the latter wind, would be able to say, not only whether there would or would not be rain among the Welsh mountains, but also what would be the character of the rain, whether it would be slight or heavy. If the dew-point was near to the temperature, as soon as the wind climbed the mountains to a small extent, it would be sufficiently cooled to condense much

of the vapour that it contained, when large cumuli would be *formed about the mountains at a moderate* height, and an *ascending current created, towards which fresh air would* rush, and a stronger wind would be the result, with heavy rain in the part. If, on the contrary, the dew-point was greatly below the temperature, the ascent of the air against the side of the mountain would not cool it sufficiently to condense any of the vapour, and the atmosphere would remain clear. But if the dew-point was in an intermediate state, clouds might be formed at some height, and either with slight rain or without any rain. Suppose, for instance, the temperature of the wind to be 60° and the dew-point 58°, in that case, when the wind had climbed 600 feet, cloud would begin to form. As the wind ascended higher, condensation would become more energetic, and, however moderate the wind had been before, it would now become stronger. If the dew-point was 56°, condensation would commence at 1,200 feet. At 54°, 52°, and 50°, the heights at which condensation would commence would be respectively 1,800, 2,400, and 3,000 feet. Should the dew-point be at so low a temperature as 48°, no cloud would be formed by the ascent of air, as the height of the mountain is only 3,560 feet, while the point of condensation would be 3,600 feet.

But cloud and rain may be formed in another way. Suppose the same air, with a dew-point of 58°, to be moving very slowly on a summer's morning, and the sun to warm it near the surface of the sea or land successively, so as at last to raise it say 600 feet, and suppose the air so raised flowed against the mountains, it is evident that it would then have but little additional height to rise before condensation would commence. Or if there was a perfect calm, then the lower part might be warmed by the sun sufficiently to produce cumulous cloud, which might go on increasing until large masses of cloud were formed and rain fell. From these facts it is evident that attention to the state of the dew-point may, in such a part,

enable a person to tell in the morning whether it is likely that there will be rain during the day. The daily action of the sun, in warming and raising air and forming cloud, generally takes full effect before three o'clock in the afternoon; and if by that time rain do not fall from the cumuli which have been formed that morning rain from them need not be expected during the day; though it may be produced, through the air being forced up mountains, by a horizontal current.

Rain, in England, commonly comes from the south or west, because the winds which come from those quarters have generally a higher dew-point than other winds; but air which has rested on the north sea, until evaporation has produced a high dew-point, may be sufficiently saturated with vapour to commence condensation on being either raised by the sun or forced up a hill.

In the summer and autumn, from the flat shores of Lancashire, when the weather is calm, a thick mist is frequently to be seen resting on the sea in the morning, which mist is generally raised by the action of the sun on the lowest stratum of air, until a well-defined stratus cloud is formed at some certain height; and, the dew-point being sufficiently high, by ten, eleven, or twelve o'clock, little protuberances begin to appear on the upper edge of this cloud, which soon swell into irregular cones, until either rain falls, or the cloud ascends to higher regions and dissolves, as the sun goes down. Occasionally, when this stratus has ascended a few hundred feet, and the protuberances are forming on the upper edge, the misty lower part of the atmosphere appears to separate into vertical films, with transparent spaces intervening, the whole presenting a view to the spectator of an immense hall or theatrical stage, hung with flags of film, some of them slightly tinged with prismatic colours. There is, at the same time, that peculiar tremulous motion which suggests the idea that warm air is ascending. From the whole of the appearances

it may be presumed that they are results of the ascent of warmed, and therefore transparent air through the mist, in separate vertical columns or streams, as they proceed to the upper part of the cloud, there to be condensed and form the cauliflower-like tops of the cumuli.

Among mountains these cumuli sometimes swell and rise to a great height, and take a cylindrical form, with hemispherical tops, when heavy rains almost invariably fall. From the high grounds near Ramsey, in the Isle of Man, clouds of this description may frequently be seen, at the same time, over Down, Wigtonshire, and Cumberland; and, from the heights of the clouds, and their approximation to the cylindrical shape, the observer may form an opinion respecting the quantities of rain falling in the parts. The clouds that accompany thunder storms, with sudden and heavy rains, are lofty cumuli, with hard outlines, the tops sometimes changing their shapes with considerable rapidity, as the vapour varies its direction in the ascent.

Influence of Forests on Climate.

Writers have frequently attributed to the presence of forests, or to their absence, the prevalence of a moist and cold or of a warm and dry climate. Malte Brun, adopting the facts and opinions he finds in books, says—"In the Cape de Verd islands, it is the burning of the forests which has dried up the springs, and rendered the atmosphere sultry; Persia, Italy, Greece, and many other countries, have thus been deprived of their delightful temperature. The cutting down of the forests which once covered the Pyrenees has rendered the air very unwholesome in the valley of Azun, because the absence of that barrier now permits a free passage to the southern winds. Similar complaints are made in Castile and Arragon."*

* See Malte Brun, vol. i. p. 408.

The idea that giving a free passage to winds makes the air very unwholesome seems strange, but we may suppose that the fact given is substantially correct, namely, that the place, from the operation of some cause, has become less wholesome since the trees were cut down. The almost universal opinion, founded on experience, seems to be, that the removal of trees, and the leaving of the land exposed to the full influence of the sun's rays, make the climate drier and warmer. In parts of the United States of America, experience is said to have shewn that cutting down the forests, and exposing the earth to the sun, renders the place drier and more salubrious, as the wood fever disappears.

But whatever may be thought of the healthy or unhealthy effect of clearing forests, there appears to be no doubt entertained that greater dryness is a consequence of such a proceeding; as, according to numerous accounts, the earth then ceases to be equally moist, and the springs to furnish an equal quantity of water. But in what way does a forest furnish an additional supply of moisture to the earth, and of water to the springs? If trees produce these effects, they must, in some way, cause more water to come to the part: and the question is—how is this effected? It has been said that they absorb moisture from the atmosphere, but that would tend to make the air dry instead of damp, and there is a contradiction in supposing that trees, at the same time, make the atmosphere damp by their evaporation and dry by their absorption. The fact, however, seems to be established from experience, in different ages and in various countries, that the presence of forests really made the climate comparatively wet, and their removal made it dry; but, in assigning a cause for these facts, we meet with the most crude and contradictory notions. This has, doubtless, arisen from the imperfect knowledge which has existed of the causes that determined the distribution of the supply of water, received from the atmosphere, to the various parts of the surface of

the earth. That the chemical and physiological processes which are going on in trees do not bring a supply of water to the part in which they grow, must be evident. Trees do not, by chemically uniting oxygen with hydrogen, form water. And it is not conceivable that they can take vapour from the atmosphere by absorption, convert it into water, and convey that water through their roots to the earth, and thus furnish a supply of water which shall appear in the moistened soil and flowing springs; for if they did this, they would make the atmosphere dry, and it is known that they make it moist. But if water cannot thus be furnished to the earth by trees, and if they yet do cause the climate to be more moist, and springs to flow more abundantly, as is generally declared, it can be only by causing more rain to fall, and this we propose to shew is effected by a mechanical and not a chemical operation.

In the *Quarterly Journal of Science*, for 1829, page 93, there is a brief review of a translation of a work from the French of M. A. Moreau de Jonnes, which obtained a prize from the Philosophical Society of Brussels. In chapter first of this work, the author maintains that woods lower temperature, "on account of their dark colour," and because "they keep the soil damp." The reviewer thinks that the experiments cited by the author are so detached as to leave room for considerable objection. But both author and reviewer agree that the clearing away of woods makes the temperature of countries warmer.

In chapter two, the author attempts to shew that woods, in flat countries, do not perceptibly increase the quantity of rain, but that on mountains they have an influence in producing that effect. And he maintains that the progressive diminution of rain in the south of Europe, which is stated to have taken place, is to be ascribed to the destruction of the mountain woods. But the way in which the woods are supposed to have produced the rain is not pointed out. In chapter four,

it is asserted that countries, especially mountainous countries, which are covered with woods, also abound more in waters than others; but no reason is assigned, either by author or reviewer, why this should be.

It has already been shewn that one great cause which determined the quantity of rain in each country, was the existence or non-existence of elevated land. And elevated land produces condensation of atmospheric vapour, and more or less copious rain, by causing the aëriform fluids constituting the atmosphere to ascend sufficiently high to commence the process of condensation of vapour. Now if elevated land, by forcing the air to rise in the atmospheric space, causes condensation, it is evident that any other cause which shall, in like manner, force the air to rise in any particular locality, may produce a similar result. And if it can be shewn that forests have this effect, it will at once account for the fact so long observed, that the existence of forests renders the climate wet, and their removal makes it comparatively dry.

Any person looking from a mountain, on a cloudy storm raging in a valley below, may observe that the lower part of the storm moves with less velocity than the upper part, producing an irregular rolling or tumbling motion of the clouds, that evidently arises from the resistance which that part of the wind encounters that presses on the surface of the earth. The frictions and obstructions on each particular part of the surface impede the progress of the lowest part of the air, and that other portion, which immediately follows, climbs over the lowest stratum of air, but in so doing it is itself impeded by the obstacle it has to encounter in the lower and retarded air. A third portion of air then climbs over the second, and in so doing is itself retarded; and in this way successive strata of air follow and climb over other strata that present obstacles to their progress, and thus form overlapping and rising currents, moving with increasing velocities as they proceed at a greater distance from the obstructions on the surface of the earth.

And in proportion to the general force of the wind will be the comparative retardation of the lower, and the overlapping, *climbing, and ascent of the upper strata.* If the air so proceeding *is free from cloud, but sufficiently charged with* vapour, when it reaches a certain height, a part of that vapour will be condensed through a reduction of temperature, and cloud will be formed, and the vapour being sufficiently abundant, rain will fall. This process must take place, to a greater or smaller extent, during every storm, even when the surface of the earth is bare, and consequently presents comparatively little resistance to the wind. But when such a storm encounters a forest, the resistance that it meets with is materially augmented, and the retardation of the lower strata is greater, the overlapping and ascent of the currents are increased, more abundant condensation takes place, and more rain falls, making the place wetter than it would be if the forest were absent, and the bare ground alone left to retard the progress of the lower portion of the wind.

That the additional resistance presented to the wind by a forest is sufficiently great to produce considerable effects on the movements of the atmosphere, is apparent. The force exerted in bending the trees of a forest during a storm is very great; and nearly an equal force to that which is exhibited in bending the trees must be exerted by the air which presses against the trees in resisting the progress of that portion of the atmosphere which immediately follows; and that following portion will be retarded, in its lower part, by a force nearly equal to that by which the trees are pressed by the wind. But, as the resistance is from below alone, and the wind can proceed upwards, it takes an upward direction, until the lower strata of the air in contact with the trees, or near to them, by their successively diminished velocity, present an inclined plane of resistance to the air that follows, which forces it to ascend; the lowest stratum being the most retarded, and the diminishing retardation being communicated successively to

the higher strata, and reaching to an elevation proportioned to the force of the wind and the height of the trees. Thus we see that a forest, by presenting resistance to wind, to a certain extent forces that wind to rise, as, in other instances, it is forced to rise by the sloping sides of mountains, and both causes are capable of producing condensation of vapour and rain.

Attraction of Clouds by Mountains.

It is common to find, in the works of intelligent writers, allusions to the attraction of clouds by mountains. Such attraction seems to be assumed as a fact, the existence of which there was no room to doubt; and the movements of clouds towards mountains, so generally observed, has been universally attributed to this attraction. Malte Brun speaks of vapours and clouds being attracted by mountains. Thus he says—"Mountains act upon climates in two ways: they attract the vapours suspended in the air—these vapours, by their condensation, produce clouds and fogs, which conceal the summits from our view."* And Captain Fitzroy says—"The islands of the dangerous archipelago have no hill or height of any kind, about which clouds attracted by them, taken together, can gather and discharge a portion of the contents."† And this is the general language of writers on the subject.

It requires very little reflection to perceive that the movements of clouds towards mountains are not likely to be an effect of the attraction exerted by the mass of the mountain on the matter contained in the cloud. The force of attraction of the mountain, as compared with that of the earth, is as the respective weights of the two masses: the force of attraction

* Malte Brun, vol. i. p. 408.

† Captain Fitzroy, p. 507.

of the largest mountain, as compared with that of the earth, is, therefore, so small as to be scarcely appreciable. But *whatever that force may be, it can only be exerted in collecting round the mountain a cone of air of a little more density* than that which exists in the atmospheric space, at the same elevation, at a distance from the mountain, just as the earth, by its attraction, collects the whole atmosphere around itself. Such a cone of air about a mountain may be conceived, but cannot be traced. When a cloud is floating in the air towards a mountain, as is often seen, its specific gravity cannot be materially different to that of the air in which it is suspended, for if it were it would fall rapidly to the earth; and yet it could be in consequence of its superior specific gravity alone that it could, in any degree, be attracted by the mountain. For if the cloud were of the same specific gravity as the adjoining air, it would, as far as attraction affected it, form a part of the cone, and would consequently be stationary, as, when once the supposed cone is formed, no cause exists for the movement of any part of it towards the mountain; it is then only the superior specific gravity of the cloud that can be acted upon by the attraction of the mountain. But if the cloud had any appreciable superior specific gravity to the air in its vicinity, it would fall not towards the mountain but towards the body having the infinitely stronger attractive force, which is the earth. And as those clouds which flow towards mountains do not appear palpably to fall towards the earth, and sometimes really rise from it, they cannot have sufficient gravity to enable the mountain to attract them. The notion, therefore, that mountains attract those clouds which are frequently seen sailing towards them, must be fallacious, and there must be some other cause for the phenomena observed, as there is no doubt about the fact that clouds do frequently move towards mountains.

Again, if the attraction of the mountain drew the clouds towards it, they would, when they had reached it, remain

attached to it. But it is common to see clouds sailing towards mountains slowly and majestically, then ascend them to some particular height, roll over their sides, and flow away with about the same slow movement as that by which they approached. Now if it were attraction that drew such clouds, the same attraction would hold them; yet they are not held, and therefore we must infer that such attraction does not exist. Sometimes clouds flow towards mountains from different and even opposite quarters, and this is frequently considered proof of the existence of sufficient attractive force in the mountain to draw the cloud. Malte Brun says—"The South Sea islands, notwithstanding their small circumference, in this manner, as in a sea breeze during the day time, attract the general east wind, which is thus made to embrace them, as it were, on every side, and to blow from all points of the compass towards the central parts of the island."* What has been already advanced will be sufficient to account for such phenomena as those just described, without being obliged to suppose that an attractive force in the mountain has been the cause in operation. But it may be here repeated, that when air charged with vapour is made to ascend a mountain sufficiently to produce any condensation of that vapour, an ascending aerial current is formed, and into this ascending current air may flow from all parts around the mountain. ¶If the condensation be considerable, the influx of the surrounding air will be also considerable, and winds will blow strongly from all points towards the mountain; and should any clouds be suspended at a suitable height in the neighbourhood at the time, they would flow with the wind towards the mountains, about which a mass of cloud would be collected. It may, perhaps, be asked what becomes of these clouds? And the reply to such a question is, that they are condensed in their ascent, and converted into rain, as shewn in an extract from Cook, in page 55. The general east wind which prevails in

* Malte Brun, vol. i. p. 385.

the Pacific was blowing at the period referred to, and that wind, when it encountered the mountains, was impelled up their sides to a sufficient height to produce condensation of a portion of the vapour which it contained; hence an ascending aërial current in the part, and the fall of rain. But as the clouds, or such parts of them as were not condensed into rain, were carried forward by the general trade wind, and descended towards the level of the sea into a warmer atmospheric region, they were dissolved into vapour, and, by becoming transparent, disappeared.

It is evident that phenomena of this kind must be modified by different causes, such as the height and shape of the mountain, the strength of the general wind, the quantity of vapour in the air, and, perhaps, by atmospheric currents flowing at different heights charged with various portions of vapour. When a cloud is formed, and that cloud is carried away by a general current into a lower and warmer region, the particles of water which constitute the cloud will evaporate and become vapour, and that portion of the atmosphere in which the evaporation has taken place, will be, temporarily, more fully charged with vapour than other portions, at the same height. In this way different local planes or levels in the atmosphere may, for a time, be charged with different proportions of vapour, one plane having a charge nearer to the maximum quantity than another. Suppose such an atmosphere to move slowly towards a mountain, and the whole to climb its ascent from the mechanical force of the wind, it is clear that the different planes in the atmosphere would present evidences of condensation having taken place in the formation of cloud according to the abundance of the vapour in each part. In the sixth volume of Cook's Voyages the following account is given:—"A volcano stands not far from the west coast of North America, and in the latitude of 54° 48′. The volcano is at the top of the cone, and we seldom saw this, or indeed any other of these mountains,

wholly clear of clouds. At times both base and summit would be clear, when a narrow cloud, sometimes two or three, one above another, would embrace the middle like a girdle, which, with the column of smoke rising perpendicular to a great height, out of its top, and spreading before the wind into a tail of vast length, made a very picturesque appearance."* Phenomena, similar in their general character, may be observed in many mountain countries. They may be seen in North Wales against the south and west sides of Snowdon. From Beaumaris, when say a south-westerly wind is blowing, there will, at times, be no cloud brought from a distance by the wind. But when this wind blows against the sloping side of Penmanmaur, and is driven up it, at a certain height cloud is formed, which, as it proceeds upwards, becomes more dense. Rain then falls from the dense part of the cloud, whilst portions of it are driven round the sides of the mountain over the Irish Sea, where they frequently dissolve by evaporation. The top of the mountain all this time may be clear, but that depends on the hygrometrical state of the air. The process and appearances described may, however, continue for hours without material alteration, cloud being regularly formed from the previously transparent air, and a part condensed into rain, whilst another part floats away and is dissolved. When a person is on the top of a mountain, whilst the circumstances just described are taking place below, the cloud may be looked down upon, and generally its upper part has an irregular white and fleecy appearance. These circumstances do not favour the notion that mountains attract clouds.

The eastern side of the Andes has already been noticed as a region of condensation, but the clouds that are formed in that region do not approach the Andes as if attracted by their large masses. The mountains are lofty, and, in many parts, rise abruptly from a low level, and if they exerted an attractive power on clouds, would draw the clouds against their

* Captain Cook's Voyages, vol. vi. p. 381.

sides, where they would adhere and take the shapes of the sides of the mountains. But such is not the state in which clouds are found in this part of the world, as will appear from the following description, which relates to a part on the eastern side of the Andes, at some distance from the tropical region of great condensation:—"March 23. The descent on the eastern side of the Cordillera is much shorter or steeper than *on the Pacific side*; in other words, the mountains rise more abruptly from the plains than from the Alpine country of Chili. A level and brilliantly white sea of clouds was beneath our feet, and thus shut out the view of the equally level Pampas. We soon entered the band of clouds, and did not emerge from it that day." Again—"March 24. I enjoyed a far extended view over the Pampas. At the first glance there was a strong resemblance of a distant view of the ocean, but in the northern parts many irregularities in the surface were soon distinguished. In the middle of the day we descended the valley, and heard that the silvery clouds, which we had admired from the bright region above, had poured down torrents of rain."* Here the air on the plains, stopped by the mountains, attained a sufficient height to produce condensation and form cloud, and this cloud, it appears, extended over the flat Pampas and was apparently equally level with them; and within this extended flat cloud torrents of rain had poured down. These facts are in accordance with the theory of condensation from cooling by ascent, but not reconcilable with the belief that mountains attract clouds. These mountains are some of the largest in the world, and they present their steep sides abruptly to the plains where clouds are formed, but there is no clustering of the clouds against their sides, like iron filings to a magnet, as there would be if this theory of attraction were true.

* Darwin, p. 401.

Storms, as they often materially affect the well-being of man, have in all times arrested attention, and have frequently stimulated inquiry into the causes which produce them, yet no satisfactory account has ever been given of those causes. Recently considerable industry has been exhibited, particularly in the United States of America, in collecting facts relating to the peculiar action of storms. Mr. Redfield has attempted to show that they are whirlwinds, with a progressive motion; and Colonel Reid, in his book on storms, has advocated the same theory. But while the facts adduced by these gentlemen are admitted to be substantially correct, the inferences from them have been disputed by Mr. Espy, who maintains that all storms are strong winds converging to a central part or line, where an ascending current exists; and he maintains that such converging winds, having a progressive motion, will produce appearances somewhat similar to those observed by Redfield and Reid, and which, he says, they erroneously attribute to whirlwinds.

As storms commonly extend over a large area, and the motion of the air during their continuance is rapid, and, to a considerable extent, irregular, it has been found difficult to collect facts sufficiently minute and accurate respecting the strength and direction of the wind in the various parts where the storm has raged. And a progressive whirlwind might certainly present phenomena so similar to progressive converging winds, as to render it difficult to determine whether the particular facts observed are more in accordance with the one theory or the other.

Mr. Redfield does not profess to give any theory to account for storms, but confines himself to endeavouring to prove that they take the form of whirlwinds, whilst Mr. Espy maintains

that storms are converging winds, and he also attempts to [illegible] what the causes are which produce these winds; and [illegible] he professes to explain the causes as well as the peculiar [illegible] of storms.

We shall attempt to shew presently that all storms are not produced in the way described by Mr. Espy; but supposing, for the present, that he is, to a certain extent, right in his theory, may it not follow that when some storm has been produced in the way he states, it may afterwards take the form of a whirlwind?

Motion in air is so rapidly communicated to adjoining air, and our means of observing the particular motions of the various parts of a large mass of air are so imperfect, as to make it difficult to detect and follow irregular movements that take place in the atmosphere, whatever they may be. But from what is known of the state of our atmosphere, we may suppose that, on condensation producing an ascending current, if the supply of vapour was equal on all sides, a nearly vertical ascent would be the result, and equal quantities of air would flow horizontally from all sides to supply the vacuum thus produced. But if one side furnished more vapour than another, there would be a greater vacuum on that side than on the other, and, consequently, a more rapid rush of air from adjoining parts of that side into the vortex, which might possibly give it a spinning motion, in addition to its ascending motion. This being admitted, it would follow that if an ascending current, with a progressive motion, should traverse a part of the atmosphere where the dew-point is higher on one side than on the other, the ascending current might first take a spiral form, and ultimately become a whirlwind.

The localities where whirlwinds are said to be the most frequent and violent, are the West India Islands in the northern, and the Islands of France and Bourbon in the southern, hemisphere. The former are within the latitudes

of say 10° and 23° north, and have a trade wind blowing on them from the east, extending in breadth say about thirteen degrees. This trade wind, by the time that it reaches the islands, is pretty fully charged with vapour, but it is to be presumed more fully on its southern than on its northern side. On the southern side, in the latitude of say 10°, the dew-point shall be say 73°, and on the northern side it shall be 70° or 65°, or some other lower point. Now, suppose an ascending current to be formed in the middle of this trade wind, about Antigua, and then more vapour would come on the southern than on the northern side, and this superior quantity, in its ascent, would, on condensation taking place, give out more heat on the southern than was at the same time given out on the northern side, and cause a more rapid ascending current on the former than on the latter side. Suppose further, the ascending current to spread and extend to the latitude of 10°, and an equal distance northward, and then this area or ring would be supplied with a quantity of vapour expressed by a dew-point of suppose 73°, or a sixtieth of the then existing whole atmosphere, from the south, while on the northern side a quantity of vapour expressed by a dew-point of suppose not more than 52°, or a one-hundred-and-twentieth part of the atmosphere, would be furnished; or the difference in the dew-points might be less than this. But as the rushing in of the air below to supply the ascending current, in any part of the ring, would be proportioned to the amount of condensation in that part, the rush of air on the southern side would be greater than that on the northern side, and this being continued, might cause the ring to revolve horizontally, at the same time that the air was ascending. Thus the wind, which, under these circumstances, would be found near the surface of the globe in the neighbourhood of the vortex, would be determined by the joint forces of the ascending and revolving currents, the ascending tending to produce converging winds and the

revolving whirlwinds, while the whole had a progressive motion produced by the general flow of the trade wind.

Colonel Reid shews that storms take place in the Indian Ocean, about the islands of France and Bourbon, in a way similar to those which occur in the West Indies. And these islands are, with reference to atmospheric currents, somewhat similarly circumstanced to the West Indies. A south-east wind generally blows from Australia, say between 20° and 40° of south latitude, towards the Cape of Good Hope, passing south of but not far from the isles of France and Bourbon, which are in 20° south latitude. And when the south-west monsoon blows strongly it is found to proceed from Madagascar towards the islands of Sumatra and Java, passing not far from the two first named isles. It is well known that the dew-point is high about these isles, and the atmosphere is often calm for a considerable period. But suppose *an ascending current to be formed near them, with* an area or ring large enough to have a part in the south-east trade wind, or in the south-west monsoon, while the opposite part was either in a calm or in the opposite wind, and we should have similar causes in operation to those which we have just traced in the West Indies, and the outer part of the ascending current might be made to spin round—or a whirlwind might be the result.

These whirlwinds are said to prevail more particularly in the localities named, but if the foregoing reasoning is correct, it is evident that whirlwinds may be formed wherever the causes which it is here supposed produced them exist. An ascending current, acted upon by an unequal supply of vapour in different portions of the outer part, may take an eddying form, as all fluids seem liable to do when in motion; and wherever vapour is most abundant, and at the same time unequally distributed, there the effects will be the greatest and the whirlwind the most powerful. In the British Islands it is probable that a south-west wind, fully charged with

vapour, may often be found blowing in the neighbourhood of a north-east wind; and supposing condensation to commence in a part of the south-west current which is near to the north-east wind, and a ring of ascending air to be created which shall enlarge until it spreads into the north-east current, then the south-west wind would be carrying the ring in one direction, while the north-east would be carrying it in the opposite direction.

It appears, then, that the whirlwinds of Redfield and Reid may exist, and may be products of the ascending currents and converging winds of Espy—condensation of vapour being the primary cause of both. But here a new question arises. Are all storms, as Mr. Espy maintains, produced by ascending currents alone? Storms are but strong winds, and it is certainly but reasonable to suppose that the same causes which produce ordinary winds produce strong ones, and create storms. Condensation of vapour being the great general cause of all the considerable movements of the atmosphere, it appears to follow, and must indeed be presumed to be true, until we have evidence to the contrary, that the most violent of these movements are results of condensation. But Mr. Espy contends, not only that storms are results of condensation, but also that they are horizontal converging winds rushing to a centre or central part, where an ascending current exists, and that all storms are thus produced, and are converging winds. Now in so moveable a body as the atmosphere, where one part so readily acts on another, it may be found that violent action of one kind may produce violent action of another kind. And if facts frequently observed in storms do not agree with the theory advanced by Mr. Espy, it may reasonably be suspected that some second cause is in operation: and we may endeavour to discover the particular action of that second cause.

When copious condensation commences in any particular part of the atmosphere, an ascending current, as has been

shewn, is formed, and a comparative vacuum created. The expansion of the air in this vacuum cools it, until more vapour is condensed, more heat liberated, and the air again warmed and raised. The adjoining air, not having the same resistance as before in the part where the vacuum is formed, expands into it, and in so expanding is also cooled: and the greater the vacuum the greater will be the expansion, and the consequent cooling. It follows from this, on Mr. Espy's theory, that in all storms, and especially in all violent ones, the barometer should fall, the wind become cold, and the thermometer should sink. For as, in the part, the barometer fell from the existence of a comparative vacuum near the earth, so the thermometer should sink from the expansion of the air in that vacuum. Now if, during the violence of a storm, the thermometer, instead of falling should remain stationary, it might be presumed that such stationary state *indicated that the storm* was not the expanding of air to fill a vacuum, *but that it was produced by some other cause.*

When air is suddenly heated and a considerable vacuum produced, and a rapid ascending current formed, a large mass of the air must be discharged in the upper regions. And this mass may be thrown on adjoining parts so suddenly as to penetrate those parts and descend again to the earth. This, perhaps, could not take place to a great extent if air alone was in motion; but the ascending current produces drops of water, and as soon as the force which carried the current upwards was expended, the force of gravity of the drops of water would cause them to fall. And in falling they might bring with them a large portion of the air that had been discharged above by the ascending current. Now such air, having been previously heated by condensation, when it reached the surface of the earth might be warm, and a thermometer placed in it would be stationary, or might even rise.

The great storm which swept over the British Islands on the night of the 6th and the morning of the 7th of January, 1839,

moved in about the direction of south-west or west-south-west, passing over Ireland and the middle of Great Britain; and when that storm was at its greatest height, say from two to six o'clock of the 7th, the atmosphere was warm to the feelings. In the accounts which appeared in the newspapers, the state of the thermometer was not often given, yet notwithstanding that the wind blew so fiercely, no complaints appear to have been made of cold by those who were exposed to the storm. At Rochdale, at five o'clock on the morning of the 7th, the barometer is stated to have been at $27\frac{8}{10}$ inches, and it is to be presumed that it was about equally low in other parts where the storm raged, though, it being night, the fact has not been noted. Now, if the wind which blew at this time consisted of air rushing by expansion into a vacuum, that air would be cooled by the expansion about ten degrees of Fahrenheit. But no cooling is noticed, and none appears to have taken place; we may, therefore, *infer that the wind which blew so furiously in this storm was* not air expanding into a vacuum.

Another striking fact appeared at Manchester during this storm. From one until five o'clock, and probably later, in the morning of the 7th, while the wind was blowing furiously, the sky was quite clear—not a cloud appearing. The storm did not here begin until after midnight; and it may be said that the heavens were free from clouds during the first four or five hours of the storm; and if that storm was merely the rushing of air to fill a vacuum caused by an ascending current, which ascending current produced clouds and rain in the higher regions of the atmosphere, why had we neither clouds nor rain at Manchester during the time? On Mr. Espy's hypothesis, with such a storm as that of the 7th January, we ought to have had a cold wind, made colder to the feelings by its great velocity, and also at the commencement, as well as during the progress of the storm, dark clouds and heavy rain; but we experienced none of these. Nor does copious rain

appear to have fallen in any part of Ireland or of England, over which the storm swept with the greatest violence.

That condensation of an abundance of vapour, and a consequent vacuum, and ascending current, perhaps over the Atlantic Ocean, may have originated this storm, is not only possible but probable: but that the storm, as it swept over these islands, was not the rushing of air to fill a vacuum, is *sufficiently clear*. It had neither the coldness, the cloudiness, nor the rain that would have been consequent on such a process. But if we suppose the ascending current to have existed, say over the Atlantic, and a large quantity of air, mixed with rain, to have been there carried up sufficiently high to have penetrated a south-west current in the higher regions of the atmosphere, which was moving with great velocity; and if we further suppose the ascended mixture of air and rain afterwards to descend, and in its descent from the height to which it had been carried, to have brought down this south-west current, moving with great velocity, to the surface of the earth, all the principal facts which appeared in this storm will seem to be natural effects. The south-west current, when thus brought down and subjected to additional atmospheric pressure near the surface of the earth, might be warm, and having come from such a height, would have but little vapour in it, and therefore would not be disposed to form rain, or even to be cloudy. And if we suppose the whole of the atmosphere in the locality, up to a considerable height, to be made up of the descended wind, the superior warmth and consequent elasticity of this thick stratum of air would reduce its gravity, and cause the mercury in the barometer on which it rested to sink. In this way we should reconcile the facts of having, at the same time, a warm air and a low barometer, which, on Mr. Espy's theory, seem to be incompatible. That a south-west wind might be moving with a high velocity in the higher region of the atmosphere, at such a season of the year, in the locality, is probable, as such wind

is known to exist, and frequently reaches the surface of the earth as a warm wind, though in a less abrupt manner than it seems to have done at the time of this storm. And sufficient reasons have been advanced to shew that extensive condensation may suddenly bring an upper current down to the surface of the earth.

Numerous accounts, in the works of travellers both by sea and land, may be found of storms which indicate that they were the outpourings of an ascended current, bringing air from the upper regions, rather than the expansion of lower air into a vacuum. Captain Fitzroy, speaking of a "pampero," near the mouth of the River Plate, states that it took place in the middle of the rainy season, the time when the vapour of the tropics is passing southward towards cooler regions, corresponding with July in the West Indies, and he writes thus:—"On the 30th January, 1829, the *Beagle* was standing in from sea towards the harbour of Maldonado. Before mid-day the breeze was fresh from the north-north-west, but after noon it became moderate, and there was a gloominess and a close sultry feeling, which seemed to presage thunder and rain. During three preceding nights banks of clouds had been noticed near the south-west horizon, over which there was a frequent reflection of very distant lightning. The barometer had been falling since the 25th slowly but steadily, and on the 30th at noon it was at 29.4 inches, and the thermometer at 78°. At about three o'clock the wind was light, and veering about from the north-west to north-east. There was a heavy bank of clouds in the south-west, and occasional lightning was visible even in daylight. There were gusts of heated wind. At four the breeze freshened up from north-north-west, and obliged us to take in all light sails. Soon after five it became so dark towards the south-west, and the lightning increased so much, that we shortened sail to the reefed topsail and foresail. Shortly before six the upper clouds in the south-west quarter assumed a singularly hard

[illegible] or tufted appearance, like great bales of black [illegible] and altered their forms so rapidly, that I ordered sail to be shortened, and the top sails to be furled, leaving set only a small new foresail. Gusts of hot wind came off the nearest land at intervals of about a minute. The wind changed quickly, and blew so heavily from the south-west, that the foresail split to ribbons, and the ship was thrown almost on her beam ends. The main topsail was instantly blown out of the men's hands, and the vessel was apparently capsizing—when top masts and jib-boom went close to the caps, and she righted considerably. Two men were lost. The starboard boat was stove by the force of the wind, and the other was washed away; and so loud was the sound of the tempest, *that I did not hear the masts break*, though holding by the mizen rigging. Never before nor since have I witnessed such strength, or I may say, weight of wind; thunder, lightning, hail, and rain came with it, but they were hardly noticed in the presence of such a formidable accompaniment. After seven the clouds had almost all passed away; the wind settled into a steady south-west gale, with a clear sky."

In this account it is to be observed that the clouds from which the storm appeared to come, were, when first observed, very heavy in the south-west, in which direction there would therefore have been great condensation of vapour and much rain formed. The ascending current, which it is presumed produced the condensation, the clouds, and the rain, was at last apparently poured out from the south-west towards Maldonado, and the rain in its descent probably forced the wind in the direction of that place. Immediately before the storm, gusts from the north-north-west came off the nearest land at intervals of a minute, when "the wind changed quickly, and blew so heavily from the south-west, that the foresail split to ribbons, and the ship was thrown almost on her beam ends." Now are not all these facts such, or nearly such, as would be likely to occur if we suppose much rain to

be formed and first carried to a certain height in the atmosphere, from which it would descend by its own gravity, but projected by the expansion of air that was taking place at a particular elevation in an ascended current? It could not be the centre of an ascending current such as is described by Mr. Espy, which was passing from the south-west towards the north, as such a current would have been first strong from the north, then a calm would have been experienced in the centre under the vortex, and then would come the south-west wind flowing towards the vortex, which would be at first rather an ascending than a horizontal current, and the increase in the strength of the horizontal wind must have been gradual. The storm could not be one side of such an ascending current, seeing that such a change in the direction, and sudden burst of strength of the wind, is incompatible with what must then have taken place. And what conceivable cause could produce such sudden "strength, or, I may say, weight of wind," as that described by Captain Fitzroy, except the one supposed—the descent of a heavy torrent of rain, expelled and projected by an expanding mass of air?

In the same book, vol. 1, it is stated that, when in the southern part of Tierra del Fuego, "at Port Waterfall, near Port St. Antonio, we noticed some extraordinary effects of the whirlwinds which so frequently occur in Tierra del Fuego. The crews of sealing vessels call them 'williwaws,' or hurricane squalls, and they are most violent. The south-west gales, which blow upon the coast with extreme fury, are pent up and impeded in passing over the high land, when, increasing in power, they rush violently over the edges of precipices, expand, as it were, and, descending perpendicularly, destroy every thing moveable. The surface of the water when struck by one of these gusts is so agitated as to be covered with foam, which is taken up by them, and flies before their fury until dispersed in vapour. Ships at anchor under high lands are sometimes suddenly thrown over on their beam ends, and the

next moment recover their equilibrium as if nothing had happened. In the Gabriel channel 'the williwaws,' bursting over the mountainous ridge which forms the south side of the channel, descend, and, striking against the base of the opposite shore, rush up the steep and carry all before them."

The south-west wind is here represented as being "pent up and impeded in passing over the land;" the barometer, however, would shew that there was no increase of density in the air when it was passing over the high land. The extreme fury of the south-west gale may, we presume, have arisen from the sudden expansion of the air in those high parts. But we are told that very heavy rains are also produced by these gales, and those rains descend to the surface of the earth. Now supposing this rain to fall from a great height near the precipice, it must bring air with it, and, increasing in power as it descended nearly perpendicularly, it might become a storm and destroy every thing moveable. Such a mass of rain and air falling on and striking against water would agitate it, cover it with foam, and the air, in its elastic rebound, might carry away the foam, as winds carry the spray of the sea, until it was at last dispersed. Sudden and copious rain falling among mountains will have a tendency to bring down air over a certain space, and momentarily to compress it into a somewhat smaller space, as the valley, lake, or bay into which the rain falls contracts in size below. And the part of the storm of wind and rain that reaches the earth may, under these circumstances, be driven down like the edge of a wedge, or the point of an inverted cone, in which is concentrated all the force exerted above, temporarily compressing the air and forcing up the barometer. It should also be recollected that the expanding air may, at certain heights, meet with descending rain, and the joint force of the two may act in all conceivable modes, particularly in the irregular spaces included between contiguous mountains. Horizontal currents of air alone evidently have not the power to produce the effects

described in the extracts. For supposing a horizontal current to be of great force, and driven up one side of a mountain, when it reached the top, and passed over the precipice, it would meet with greater resistance from below than from above, and would, consequently, be more disposed to ascend than to descend. The force of gravity of some body more ponderous than air is necessary to produce such a vertical descent as takes place in these local storms called "williwaws," and that force seems obtainable from rain alone, as no other body is present to furnish it. The figure used in the description of "bursting over the mountainous ridge" can mean no more than that the "williwaw" was first observed coming from that part. Rain might have been descending from one current, and while in that state be caught and thrown over, or off from the ridge, by another ascending and expanding current, and the projectile force with which the rain was thrown, and its own gravity, might carry it to the base of the opposite shore, where, intermingled with air, it would rush with a force proportioned to its velocity. These descending gusts of wind are almost always stated to be accompanied by rain, either in them, or near them, but the rain is generally spoken of as brought by the wind; it is, however, desirable that these phenomena should be observed with a supposition in the mind of the observer that the rain may be the cause of the wind rather than an effect of it, in order that it may be seen how all the facts will harmonize with such a supposition.

Laird and Oldfield, when in Africa, thus describe a storm on the Niger:—"There is something awfully grand and impressive in the appearance of the heavens before a tornado. A dark mass of clouds collects on the eastern horizon, accompanied by frequent loud but short noises, reminding one of the muttering and growling of some wild animal in a voice of thunder. This mass or bank of clouds gradually covers one-half of the horizon, extending to it from the zenith; but generally before this a small and beautifully formed radiant

arch, on the verge of the horizon, appears, and gradually increases. Long before it reaches the vessel, the roaring whistle of the whirlwind is heard, producing nearly as much noise as the peals of thunder that seem to rend the very clouds apart from each other. The course of the squall is distinctly marked by the line of foam it throws up, and I have stood on the taffrail of a vessel, and felt the first rush of the wind while her head sails were becalmed. The sensation it produces afterwards is cheering and delightful. From breathing a close and murky atmosphere, loaded with unpleasant vapours that invariably precede the tornado, the mind becomes relieved, as it were, from a load; the air is fresh and clear, and every thing around is fresh and exhilarating."*

Can such a storm as this arise merely from the expanding or rushing of air into a vacuum? Converging winds, moving towards a centre, cannot have in their front such an abrupt edge as this storm had; as these winds, when approaching their centres, will curve upwards. And the air which is farther from the centre, and which follows the first rush, will be, in a continuous stream, produced by successive expansions, and increasing in force up to some point; which stream however will, at a certain distance, become weaker, until it at last disappears at the outer extremity of the storm. But in this African storm the cloud was seen in the east, the roaring whistle of the wind was heard before it reached the vessel, and its locality and progressive force were distinctly marked by the line of foam which it threw up, and it came so abruptly that the writer stood on the taffrail of the vessel and felt the first rush of the wind, while her head sails were becalmed. These circumstances may be conceived to have resulted from the outpouring of an ascended current which had carried much rain into a high region of the atmosphere, where there was possibly a sudden expansion of air: or a rapid upper current might have existed, a part of which

* Laird and Oldfield, vol. i. p. 58.

may have been brought down by the descending rain, and which continued its rapid motion as described, until, at some distance, its force was expended by the resistance of the lower air: but the facts appear utterly irreconcilable with the supposition that the storm was the immediate effect of air rushing into a vacuum. We are told, too, that previously to the storm the atmosphere was close and murky, but afterwards it became clear, and every thing around was fresh and delightful. From this account the lower air before the storm was evidently fully charged with vapour, but the air which constituted the storm, if it came from a height where much vapour could not exist, must have been dry, and hence the delightful sensations spoken of.* Had we the dew-points immediately before and after the storm, it is to be presumed that they would shew a great reduction in the quantity of vapour in the atmosphere. Even the arch that appeared, when the storm was at a considerable distance, may be explained on the theory here suggested. The ascending current, in which we presume the storm originated, had its condensation commenced at some certain height, dependent on the hygrometrical state of the air, say at such an altitude as would enable a person at a moderate distance, looking at it in profile, to see the transparent space beneath the lowest level at which the cloud was formed. And as that level would be at about a uniform distance from the earth, it would take the curve of the earth, and the radiant or transparent space below would seem to have an arched top.

Descending gusts of wind have been often noticed and described in a general way. Malte Brun, when speaking of a hurricane, says—"It begins in various ways: sometimes we have a little black cloud appearing on the summit of a mountain; at the instant when it seems to settle on the peak, it rushes down the declivity, unrolls itself, dilates, and covers

* Dr. Clarke describes a storm which he encountered in the Black Sea. Chapter 25 of his Travels.

the whole horizon."* It is not easy to conceive that this can be anything but the outspreading of an ascended current, which had carried condensed vapour to some certain height, [illegible] poured it out, driving it, by the expansion of the [illegible] current, until it covered the horizon. [illegible] the British Islands, in the storms of autumn and winter, it is common for gusts of wind, frequently with rain, to come suddenly, and as suddenly to cease. Now how can it be conceived that there can be such an abrupt change, as is exhibited in these sudden storms, in the force of a horizontal current? No adequate cause for such a change can be traced. But if we suppose a local formation of rain at a considerable *height in the atmosphere, and a projection and descent of that rain at some angle determined by its own gravity, and* the direction of any current of air which may have acted upon it, or through which it may have passed, all that takes place seems natural and probable. In the southern parts of the United States of America it is said that storms are sometimes experienced which seem to alight on the surface of the earth, and ravage it for a certain moderate extent. The storm then leaves untouched a space, appearing to have jumped or bounded over it, and alights on and ravages another part, and in that way proceeds forward. Now is it not reasonable to presume that some such force as that which is exerted by the gravity of descending rain, must have been instrumental in producing the peculiar effects described? These effects may be considered local results of condensation, and a fall of rain; and when the results are of a more extensive character, they operate over a wider area;—when still more extensive, they, in time, blend with and modify each other: and instead of storms bounding along as in the United States of America, or producing such incidents as are to be seen near Cape Horn, the upper current, or that which otherwise would be the upper current, is extensively brought down to the surface of

* Malte Brun, vol. i. p. 387.

the globe, and caused to force its way against and displace a part of the lower stratum of the atmosphere. In this way the atmospheric spaces near the surface of the globe, between tropical parts and such localities as the Himalaya Mountains, Norway, Tierra del Fuego, and California, or New Albion, become occupied by a moist, warm, and disturbed aërial current, flowing from parts where evaporation has furnished vapour in abundance to other parts where that vapour is freely condensed. But a sudden descent of air in a particular locality, resulting from great condensation in that locality, may display so much energy, and produce so violent a rush of the descended air, as to make it a storm; and the force of the storm will be determined by the quantity of rain formed in the higher regions, or the velocity of the upper atmospheric current brought down by the rain, or by both causes acting together. It must, however, be admitted that the subject of Storms is surrounded with difficulties which additional information will be likely to remove.

The Irregular Fluctuations of the Mercury in the Barometer.

As the column of mercury in the barometer balances the weight of the atmosphere which rests upon it, the height of the mercury must exhibit the amount of that weight. But the height of the column alters so much, from time to time, as to make the extreme range of the alterations at the level of the sea about three inches; and, of course, the weight of the aërial column must vary to the same extent. Now, what is the immediate operating cause of this variation in the weight of the atmosphere? This is a question which has been often asked, without any satisfactory reply having been given, though many attempts have been made to answer it.

It is, however, generally admitted that the fluctuations of the barometer are, in some way, consequent on variations in the temperature of the atmosphere: many other influences have been pointed at, but change of temperature is generally presumed to be the cause, although the way in which it acts is not plain. Supposing this presumption to be correct, it removes the difficulty only a single step, as we have still to ascertain what can produce such a variation of temperature as shall alter the weight of the aërial column to the extent that is often experienced. The general average height of the mercury at the level of the sea being 30 inches, the weight of the atmosphere is, of course, equal to that height of mercury; and as the fluctuation is, in some parts, about three inches of mercury, the alteration in the temperature of the atmosphere must be great to produce such an effect.

*Within and near to the tropics the sun heats the atmo*spheric mass and causes it to expand, rise, and occupy additional space above the surface of the globe, but that does not materially reduce the pressure of the aërial column against the mercury in the barometer within the tropical regions, because the heating by the sun operates so slowly as to allow such a moveable body as the atmosphere to supply the place of the expansion above by an influx of air below, and this prevents any great disturbance of the pressure. But much of the heat of the sun that impinges on the surface of the globe is not accumulated there, but unites with water, and converts that water into aqueous vapour, which flies from the part, taking the heat with it in a latent form. Let us then endeavour to follow this vapour, and try to ascertain whether it is the heat that it contains which, by disturbing the temperature, alters the pressure of the atmosphere in certain localities, and causes the fluctuations of the column of mercury in the barometer.

There are many localities on the surface of the globe where the heat which has been taken up by evaporation is freely given out by condensation when much rain falls, but none

where the effects are of a more striking character than in the neighbourhood of Cape Horn. The solar heat taken up by the water of the Southern Pacific Ocean is, in the form of vapour, conveyed to the mountains of Tierra del Fuego, and is there, by the condensation of the vapour, when copious rains fall, liberated, and left to attach itself to that portion of the atmosphere with which it is in contact, to raise its temperature and cause it to expand. The way in which this liberated heat expands the atmospheric gases has been explained in a paper on the formation of the cumulous cloud, published in the *Philosophical Magazine* for August, 1841. It was there shewn that the liberated heat increased the elasticity of the gases, caused them to expand into a wider space, pushed the adjoining mass of air away, raised that which was above, and caused it to flow over to adjoining parts, and thus removed a portion of the weight of the atmospheric column in the locality.* This is what apparently takes place in the part of which we are speaking, the southern extremity of America, when rain falls freely. Captain Foster, who erected an observatory in 55° of south latitude, says—"The height of the mercury is perpetually fluctuating, shewing a constant change in the aerial column." And the mercurial column is generally low, as he states that "the barometer at Cape Horn, Staten Island, and New South Shetland, scarcely ever reaches 30 inches, and the mean of the year is 29.3 or 29.4." Captain Fitzroy also speaks of this locality in a similar way, as being furiously windy, and drenched with rain, but as being warm in the winter for the latitude. He has given an account of the state of the barometer in various places in the neighbourhood, and among them are observations off—

Diego Ramirez,	from January 1	to January 14—	44 times,	average 29.19
Goree Road ...	from January 15	to January 23—	46 times,	average 29.57
Berkley Sound,	from March 1	to April 6—	44 times,	average 29.47

shewing an uncommonly low average state of the mercurial column, and consequently of atmospheric pressure.

* See also page 12.

On examining the meteorological facts that have been furnished respecting this remarkable region of condensation, it will appear that we are justified in concluding that the condensation of vapour, and consequent liberation of heat, which evidently take place in the part, cause a boiling up and overflowing of the atmosphere, and that that boiling up and overflowing not only produce variations of atmospheric pressure, but prevent the atmosphere from there settling down in its full quantity and weight, and hence the low average state of the column of mercury in the barometer. Now if such causes can so affect the barometer in this part of the world, may we not infer that wherever that instrument is similarly affected, causes similar in their nature may possibly have produced the results?

In the British Islands there are extensive fluctuations of the barometer, and to those islands vapour is taken in great abundance from the West Indies and the Atlantic, and a considerable portion of it is there condensed into rain. There is, indeed, occasionally the same kind of boiling up and overflowing of the atmosphere from the condensation of vapour over the British Islands, as that which takes place at the southern extremity of America, and with the same kind, though not amount, of effect on the barometer.

But there are also localities of condensation where that condensation is great, and yet where equally great alterations of the barometer are not produced, and how is this to be accounted for? The western coast of Hindoostan, and South America, near the source of the Amazon, have, no doubt, greater amounts of condensation than either Cape Horn or the British Islands, yet they do not ordinarily experience as great fluctuations of the barometer. For this difference of results in different places, where similar causes seem to be in operation, the following reasons may be suggested. Within the tropics ordinary condensation of vapour is generally considerable in its aggregate amount, though proceeding slowly,

and a consequence of this must be, that the whole of the atmosphere will be there heated by condensation, up to a considerable height, and over a large area. It will, however, not only be heated, but raised to a greater height than in other parts, and by its superior height make up for its inferior density. And in any particular locality of condensation in such an atmosphere, an ascending current of warmed air may not rise as suddenly, nor as readily flow over at the top, or in a high part, as it would in a colder latitude, seeing that the whole atmosphere is there warmed, and raised to a greater height. If this view is correct, even local condensation within the tropics will result in contributing, in a greater degree, to the general overflow of the tropical air, than in any particular overflow in the locality which shall affect the atmospheric column at the surface of the earth.

When condensation takes place near the surface of the globe, the whole effect of the removal of a part of the incumbent air is experienced near the surface within a small area, and each and every part of that area is materially affected; but when the condensation occurs at a greater elevation, the effect of the removal of the same quantity of air is spread over a larger area, and the surface, in every part of that area, is less affected. The alteration in the pressure of air on the mercury in the barometer will, therefore, be proportioned, not to the amount of condensation alone, but also to the extent of area over which the lightening effect of that condensation is spread.

Again, when condensation takes place contiguous to the surface, nearly the whole atmospheric column is affected by the heating, and the lower and denser part is raised; but when that condensation occurs at a considerable *height, the denser part of the atmosphere is not expanded by the heat, but that expansion is confined to the rarer part above.*

Say that the density of the atmosphere at the surface of the earth shall be expressed by 1.00000

then at the height of	5,000 feet it will be		as...	.82656
at	"	10,000 feet	" as...	.68321
at	"	15,000 feet	" as...	.56472

so that at the last named height the density is not much more than one-half of that of the surface. Condensation at the height of 5,000 feet would expand air of more than three-fourths of the density of that at the surface, whilst the same amount of condensation at the height of 15,000 feet would have air of little more than half the surface density to act upon. It will follow from this statement that, with an equal amount of condensation, the barometer will be less affected in the tropical regions than in the colder latitudes, from two causes—first, from the superior height at which that condensation takes place, spreading the reduction of atmospheric pressure over a larger area, and, secondly, through the condensation taking place in more attenuated air.

Suppose condensation to some given extent to take place over London, at a height of say 3,000 feet, and that the consequent increased elasticity of the air at that height should throw off a part of the column of air that rested on London. As the comparative vacuum was formed at a height of only 3,000 feet, it is evident that the reduction of atmospheric pressure on London would be more than it would be if the same amount of condensation took place at a height of say 6,000 feet. In the former case the whole effect might be confined to London, and a barometer placed in any part of it would fall considerably, whilst, in the latter case, the same amount of reduction of pressure would be extended over a wide area, and each part of the surface within that area would be but slightly affected by it. Now we have only to conceive that at Bombay, or at any other part within the tropics, condensation generally takes place at the height of 6,000 or 9,000 feet, whilst at London it occurs at a height

of 3,000 feet, to account for the different effects on the barometer of the same amount of condensation in various latitudes. Were it not for the larger amount of condensation that takes place within the tropics, and parts under tropical influences, the effects on the barometer would probably be scarcely traceable in those parts.

An increase in the temperature of a limited portion of the atmosphere of one degree causes it to occupy, under ordinary circumstances, a four hundred and eightieth part more space; the remaining weight in the original space will consequently be less by a four hundred and eightieth part. A sudden increase of temperature of one degree, in any particular locality, in the atmosphere, would, therefore, reduce the weight of the air in the part to the extent named: and the mercury of a barometer placed in the part would exhibit a fall to a corresponding extent. A greater increase of temperature would of course have a proportionally greater effect. The following table shews what would be the reduction in the weight of the atmosphere, and the consequent fall of the barometer, if a limited extent of that atmosphere had its whole column suddenly heated to the degrees named:—

Increase of Temperature.	Proportional reduction of weight of the Atmosphere.	Fall of the Barometer.
1°	a 480th part	$\frac{1}{16}$ of an inch.
2°	a 240th "	$\frac{1}{8}$ of an inch.
4°	a 120th "	$\frac{1}{4}$ of an inch.
8°	a 60th "	$\frac{1}{2}$ of an inch.
16°	a 30th "	1 inch.
32°	a 15th "	2 inches.
48°	a 10th "	3 inches.

From this table we see that an increase in the temperature of the whole column of the atmosphere, within a particular locality, of only 4°, would be sufficient to lower the barometer to the full extent that it ordinarily ranges within the tropics. But if only a part of the atmospheric column has

its temperature increased, then a greater increase, in that part, would be necessary to cause such a reduction in weight as is pointed out in the table. To produce a fall of three inches of mercury, the temperature of the whole column must be raised 48°. There are places in the world, as in Yakuts, in Siberia, where the temperature is sometimes as low as 90° below freezing; and should condensation of vapour take place where the temperature is so low, the local temperature might be raised to, and for some time be kept at, the freezing point, and of course be raised 90°. For conversion of vapour into water might raise the temperature to or even above the freezing point; and if the extreme cold of the part should soon cool down some of the particles of water, and convert them into snow, the congelation would give out fresh heat, which might, for some time, keep the temperature up to 32°. Here, then, would be a local difference of temperature, not of 48°, as is shewn by the table to be required to lower the barometer three inches, but of 90°. We are not, however, to suppose that the whole column would ever be *thus warmed,* but the part where condensation forms a cloud might exhibit a rise of full 90° of temperature above that of the air in the neighbouring parts at the same altitude.

It has been shewn that the upper parts of the atmosphere in the temperate regions are not as regularly and abundantly supplied with heat, by the condensation of vapour, as those of the tropical regions, and, therefore, the upper parts of the temperate regions will more nearly take the temperature due to the latitude and elevation alone: condensation will, consequently, there take place at a lower elevation, and the reduction of atmospheric pressure, which follows condensation, will be experienced in the locality at the surface of the earth, in any particular part of it, in a stronger degree, which will be shewn by the alterations of the barometer. Mr. Daniell says—" Between the tropics the fluctuations of the barometer do not much exceed a quarter of an inch, while beyond this

space, they reach to three inches."* And Dr. Dalton says that "at Kendal the mean range, for five years, was 2.13 inches—the greatest range was 2.65 inches." But all parts of the temperate regions will not be affected alike in this respect. The currents flowing from the tropics, which are found in those temperate regions, carry with them tropical influences, and the barometrical movements within them, will, according to their distances from the tropics, be affected by those tropical influences. Thus the higher regions of the atmosphere in the south-west current of the Atlantic, and of Western Europe, will be warmed by the influence of ascending vapour to a greater extent than will be found over the northern parts of the continents of Asia and America: and with equal amounts of condensation, at any one time, the fluctuations of the barometer will be greater in the latter than in the former parts. The same reasoning will equally apply to all the other return tropical currents. This tropical influence will also be the greatest at that period of the year when the most abundant supply of vapour is obtained from the tropics. It will thus be found that, should condensation at some particular period take place over the northern part of the continent of Asia, or of America, to an extent equal to that which is going on in the same latitude in the return tropical current, it will produce a greater effect in the former than in the latter part, on a barometer placed on the surface of the earth, because in the former case the condensation will be effected at a lower level. Accounts given by Dr. Dalton are in accordance with these views. The Doctor says—"In the temperate zones the range and fluctuations of the barometer are always greater in winter than in summer;" and that "the barometrical range is greater in North America than in Europe, in the same latitude." The height at which condensation takes place in different seasons and latitudes may be conjectured from the heights at which clouds form.

* Daniell, p. 108.

Dr. Dalton represents their under sides as being below 1,300 yards in winter and 2,000 yards in summer. Clouds are represented by Humboldt to be much higher in tropical America than in Europe, and they probably are generally so in all parts of the tropics.

The mean height of the barometer, in a cool latitude, is lower in a region of great condensation than in a dry region, other circumstances being alike, because in the former the whole atmosphere is, to some extent, heated, expanded, and a portion made to flow over to adjoining regions, thus making the whole remaining portion of less weight than before; in the dry region, no such general heating takes place; and the air, being thus left cool, settles at its full density and weight. And the barometer falls and rises over extensive areas at the same time, in so similar a manner, as to indicate that some common cause affects the weight of the atmosphere throughout the whole of the area; because whenever a broad current of air, highly charged with vapour, flows to a considerable distance, condensation may take place, and the pressure of the atmosphere be reduced, at the same time, over the whole area of the current. The atmospheric current that flows over the west coast of Europe is broad, and it extends from America to beyond Switzerland, and in that range we may have such an overflow of the warmed air as shall reduce the weight of the aërial mass throughout the whole of its extent at or about the same time. It is not necessary that this should be the effect of a single swelling produced by condensation as large as the area, but it may be any number of smaller ones, and they may run into each other, and the whole may have a joint effect on the barometer, though the influence of any particular local ebullition may be traceable. The upper part of the atmosphere in this locality, in the autumn or the beginning of winter, may be conceived to rise and overflow to the westward on North America, and to the eastward on Northern Asia. In the summer the overflow may be more to the north, as it

is presumed that the descent of the warmed air will always be in that direction in which the coldest, and, consequently, the shallowest atmosphere exists. Cape Horn is a locality of great condensation, surrounded, at some certain distance, by air of a temperature and density due to the latitude alone; now, on heat being liberated by condensation about Cape Horn, the air will boil up and overflow, and less than the average weight will be left to press on the surface of that part of the globe. And the supply of vapour being sufficiently constant to cause the boiling up and overflowing to continue, this inferiority in quantity and weight of air in the part may continue, and the barometer may, through all its fluctuations, mark a low average degree of atmospheric pressure. It is possible that the barometer shall be occasionally low when the weather is fine, if it be placed in the centre of a large area of condensation, where the rain produced is poured outward, on all sides, from the centre. It is indeed evident that there may be neither clouds nor rain in the centre of such an area as that described, when condensation has continued for some time, as no supply of vapour may reach that part, all having been intercepted in the outer portions of the area.

In other localities we find a current of air cool and dry for the latitude, and consequently almost without condensation. In these we may expect to have the full weight and pressure of the air, and the barometer to range accordingly. Such localities appear to exist about the Cape of Good Hope and Valparaiso. These places may even have the barometer standing above the general mean height, as they are so situated as to be likely to receive an overflow of air from neighbouring regions of condensation which has been cooled in its descent. The Cape of Good Hope is placed in the great south-east current which is passing towards the tropical regions, and may possibly receive an overflow from the return current, which, proceeding from the southern tropic, blows

fr[illegible] of the Cape, and is, as Captain Hall says, "generally tempestuous.' Valparaiso experiences but little rain, and has, therefore, we presume, its full quantity of air, and may also receive an overflow from the region of condensation south of it, and may, consequently, have a high barometer. It is very likely that in all regions of copious and continued condensation, particularly in high latitudes, the mean of the barometer will be found low; and that where the air is generally both cool and dry, it will be comparatively high, the disturbing and lightening causes being, in some places, such as Cape Horn, so constant as to produce that departure from equilibrium of atmospheric pressure to which air always tends. If this view is correct, all aerial currents, proceeding from cooler regions, towards the equator, and containing but little vapour for the temperature, will have a barometer which may be placed in their range comparatively high, whilst all currents in which condensation is taking place freely will shew a barometer comparatively low.

The following observations, by Captain Foster, have a bearing on this subject. He says—"At the Cape of Good Hope the barometer ranges, throughout the year, from 29.7, the minimum, to 30.6, the maximum, the mean state being 30.[illegible]. The barometer has a higher range in winter than in summer. The average difference between the atmospheric pressure of Cape Horn and the Cape of Good Hope is nearly one inch of the barometer. At Valparaiso, on the coast of [illegible]li, the barometer stands equally high as at the Cape of Good Hope. Are there not (says Captain Foster) zones of [illegible] pressure as well as of temp[illegible] The mean [illegible] fluctua-[illegible] of [illegible] the year, [illegible] of 40°, [illegible] 30.[illegible] inches, and a [illegible] amounting to an inch or

an inch and a half. Again, in the cooler latitudes, from 40° to 60° and upwards, there is an unequal and fluctuating range, the mean pressure being below 30, and about 29.8, with a wide range from 28.1 to 30.8, being 2¼ inches." "In the Island of Ascension, the barometer never rises above 30.1, nor falls below 29.8—the mean for the whole year is 29.95."

Mr. Daniell says—"As we advance towards the polar regions we find the irregularities of the wind increased, and storms and calms alternate without warning or progression;" and he goes on to say of these regions, quoting from Scoresby, that "the extremes of heat and cold will sometimes prevail within a very limited compass, and forcible winds will blow in one place, when at a distance of a few leagues gentle breezes prevail. Ships, within the circle of the horizon, may be seen enduring every variety of wind and weather at the same moment; some under close-reefed topsails, labouring under the force of a storm,—some becalmed and tossing about by the violence of the waves,—and others plying under gentle breezes, as diverse as the cardinal points. The fluctuations of the barometer are also great and sudden." The causes which produce ascending aërial currents must, in the regions here described, act in an isolated manner on small extents of surface, as they produce such different results within so small an area; but the fluctuations of the barometer shew that those causes greatly altered the weight of the atmosphere within small distances.

In the very cold polar regions but little vapour exists in the atmosphere. The water, too, is generally covered with ice, which obstructs evaporation. But there are occasionally holes and openings in the ice, and in these situations evaporation takes place freely. The temperature of the air being say 70° below freezing, not very uncommon in these parts in the middle of winter, the probability is that the dew-point would be still lower. Now on water of 32°, in the openings

of the ice, being exposed to air, with a dew-point of say 70° below freezing, evaporation would take place about equal to that which would arise from water of 110° in air with a dew-point of 40°, which is often the state of our atmosphere in this part of the world in cool weather. And we know that much vapour rises from water of 110° in such weather. Vapour would, therefore, spring freely from the water, taking with it a part of the heat which the water contained. But in such a cold atmosphere as that under consideration, this vapour would be almost immediately condensed, and made to give out its heat to the air; and the air, thus heated, would rise; and this process of evaporation and condensation being continued, an ascending current of comparatively warm air must be formed, commencing from a level near the surface.

With a temperature of 70° below freezing, when evaporation takes place from the surface of water, and vapour passes into the air, not only does condensation of the vapour soon follow, but congelation also of the particles of water produced by the condensation. There is, therefore, a double liberation of heat—first that which was latent in the vapour, and next that which was latent in the water; and both these quantities of heat are given out to the air and warm it: and this double process takes place wherever cloud, and snow or hail are both formed in the air. Now in such an atmosphere, suppose a considerable area of water of 32° to be suddenly exposed by the removal of ice, and the following phenomena, it would appear, must occur. First, vapour would spring freely from the surface of the water into the air, where a part of it would be almost immediately condensed and its heat liberated, producing the commencement of an ascending aërial current. This current would take the remainder of the vapour, together with the particles of water, to a higher level, where fresh condensation would take place, and thus the process would be repeated, and any little vapour that was previously in the atmosphere would be

height, be condensed and form a cloud. At a certain stage in the process the great cold of the part would freeze the small particles of water which constituted the cloud, and convert them into snow, thus furnishing more heat to feed the ascending current, which would, consequently, rise rapidly, and expand over the neighbouring regions of the cold and dense, and therefore low, atmosphere, leaving a smaller weight of air to press on the surface of the earth, in the particular part where the condensation and congelation had taken place. A barometer placed in this particular part would shew evidence of greatly diminished pressure, because the base of the heated air, which produced the ascending current, was near the surface of the earth where the barometer was placed.

In parts of the polar regions where the temperature is much below freezing at the surface of the earth, clouds are occasionally seen. These clouds may be formed from vapour brought from warmer regions by an upper current, or from other vapour, the product of recent evaporation in the part. But from whatever quarter the vapour may come, the liberation of its heat, by condensation, will tend to raise the temperature of the part of the atmosphere where the condensation takes place, as high as, or even higher than 32°, and the buoyancy of the part, and the rapidity of the ascending current, will be proportioned to the difference of temperature between the cloud and the cold air adjoining of the same altitude. Now, on some particles of water in a cloud being converted into snow, the latent heat would become sensible, and the intermixture of the snow and the remaining particles of water would be disposed to take the temperature of 32°, for the same reason that snow or ice put into water would cause the mixture to take that temperature. Consequently, when snow of a lower temperature than 32° falls to the earth, that lower temperature may have been acquired, not in the part where the freezing took place, but in some other part through which the snow subsequently passed. However cold,

therefore, it may be at the surface of the earth where snow is falling, we may conclude that, in the part of the atmosphere where it was formed, the temperature at the time of its formation was not lower than 32°. It follows from this that a great formation of snow, in a very cold part, must give considerable buoyancy to the atmosphere in the part where it is formed, and must cause a local rise and overflow; and, the buoyancy commencing near the surface of the globe, would be attended by a considerable fall of the barometer in the locality.

Captain Parry has various passages descriptive of what takes place in the polar regions. He says—"While the atmosphere near the ships was so serene and undisturbed, that the smoke rose quite perpendicularly, we saw the snow-drift on the hills, at one or two miles distant, whirled up into the air in columns several hundred feet high, and carried along by the wind sometimes to the north, and at other times in the opposite direction."* The Captain does not say what produced this ascending current; but if a barometer had been placed under it, it is probable that the mercury of that barometer would have suddenly fallen, while another near the ships might not have been affected. In another part he says—"When any great extent of water is seen, the frost smoke, of course, is very much increased, and entirely hides the horizon from the view, seldom, however, rising above 2° in altitude, and presenting, by its dusky grey clouds, a fine foil to the matchless blue of the sky in frosty weather."† Here the intense cold in the part soon converted the vapour which arose into minute particles of water, and formed cloud, but the cloud itself was, by the same cold, frozen before it could reach any considerable height. The following passage will shew the result of such congelations;—"The deposition of small snow, which I have observed as almost always going on in these regions in the winter, took place this evening in occasional showers, so thick

* Captain Parry, p. 252. † P. 94.

as to oblige us to cover the instruments with which we were observing, though the stars were plainly visible all the time, and the night was in every other respect what would generally be called clear."*

Hail cannot be formed in such a climate, because the watery particles constituting cloud cannot be carried sufficiently high to enable large drops of water to form before congelation commences. The fact of the non-formation of hail in cold climates had been noticed by Dalton, who observes that "it scarce ever hails in latitudes higher than 60°." And he says, in another part, that "in winter, during a frost, if it begins to snow, the temperature of the air generally rises to 32°, and continues there whilst the snow falls."†

From other facts observed in the cold regions named it would appear that the air, warmed by the condensation of vapour in the higher part of the atmosphere, frequently descends to the lower region at some distance from the place of its ascent; hence, perhaps, the thaw which often succeeds to a fall of snow in our temperate climate. In the polar regions the great change which must be produced in the temperature of the higher parts of the atmosphere by condensation, causes that change to be felt in the lower part in a more sensible degree than in warmer latitudes. This change is noticed by navigators when speaking of the rise of temperature which accompanies a wind. In Parry's first voyage to discover a north-west passage, in 1819, we have the following statement:—"*From midnight on the 29th till two o'clock on* the following morning, the thermometer rose from *—46° to —40½°*, and at half-past three a gale came on from the northward, which continued to blow and the thermometer to rise *till the latter had* reached —21° at midnight. This was one of a great many instances which occurred during the winter of an increase of wind, from whatever quarter, being accompanied by simultaneous rise in the thermometer."‡

* Captain Parry, vol. iii. p. 165. † Dalton, p. 133.
‡ Parry, p. 199.

Again—"From 4 P.M., on the 14th (February) till half-past seven on the following morning, being an interval of 15½ hours, during which time the weather was clear and nearly calm, a thermometer, fixed on a pole, between the ships and the shore, never rose above —54°, and was once during that interval, namely, at six in the morning, as low as —55°. *This low temperature might perhaps have continued* much longer, but for a light breeze which sprung up from the northward, immediately on which the thermometer rose to —49°, and continued still to rise during the day, till at midnight it had reached —34°."*

In a region so intensely cold as this was, any considerable amount of condensation must have greatly raised the temperature in the part where it took place, and must have produced an ascending current. Yet the first effect of the ascending current on the adjoining lower air must have been to cause it to expand, and, therefore, to become somewhat colder. But as the thermometer showed that the wind became warmer, it is reasonable to infer that warmed air had in some way come down to the surface of the earth, for from what other quarter could it have come? And it is not improbable that portions of the atmosphere, under such circumstances, may take a form approximating to that of a vertical wheel, ascending in one part and descending in another; at some distance from which other part the descended warm air may flow towards the ascending vortex, and constitute a warm wind. But as the wind thus warmed would be dry, it could not continue to furnish the ascending current with vapour, and, therefore, the process would soon cease.

From these facts and reasonings it appears that the greatest fluctuations of the barometer must arise from the partial heating of a portion of the atmosphere where it is cold and shallow; as then the heated air will rise rapidly, and overflow to adjoining parts, and the effect of the removal of a part of

* Parry, p. 237.

the heated column is experienced at so small a distance from the surface of the earth as to cause it to be confined to a small area, within which area the atmospheric pressure is materially diminished, and the mercurial column sinks. In the temperate regions, and more particularly in the warm and moist parts, the base of the column of heated air will be at a greater distance from the surface of the earth, and the effect of any overflow will be extended over a wider area, whilst it will be less in each particular part. Within the tropics, and in parts with moist tropical climates, the base of the heated air will be still higher, and among more attenuated air, the range of the effect wider, and the influence will be found less on each separate part of the surface. And thus, the amount of condensation of vapour being the same, the more extensive the area affected the smaller will be the reduction of atmospheric pressure within it, and the less the fall of the barometer at any one point.

The Semi-Diurnal Oscillations of the Barometer.

We now come to consider the causes of those semi-diurnal oscillations of the barometer which have excited so much attention in many parts of the world, and which have hitherto defied all attempts to explain them. Contrary to what is experienced in the irregular fluctuations, these semi-diurnal oscillations are the greatest in tropical parts, and diminish considerably in the temperate regions; whilst they are, probably, extremely small near the poles.

In the ninth volume of the proceedings of the British Association for the Advancement of Science, is a report from Mr. W. S. Harris, on 26,280 hourly observations of the height of the mercury in the barometer, at Plymouth, in the years 1837, 1838, and 1839. From this report it appears,

that during these years, the mean daily pressure of the atmosphere was equal to 29.800 inches of mercury very nearly, which is exhibited on a diagram shewing the risings and fallings during the twenty-four hours. The times of rising and falling are—

1st period, 6 hours, from 4 A.M. to 10 A.M.
2nd period, 6 hours, from 10 A.M. to 4 P.M.
3rd period, 6 hours, from 4 P.M. to 10 P.M.
4th period, 6 hours, from 10 P.M. to 4 A.M.

And the following is a table of the heights of the mercury at the four turning periods, namely, at

Hours.	4 A.M.	10 A.M.	4 P.M.	10 P.M.
Inches.	29.793	29.806	29.790	29.810

In the diagram curve, given at the end,* representing the mean pressure, and the risings and fallings of the mercury, together with the table of the heights of the four periods, it will be seen that the morning rise, from four o'clock, commences from a height of about 29.793 inches, and by ten o'clock reaches 29.806 inches. And the evening rise commences at four o'clock, from a height of 29.790 inches, and by ten o'clock at night reaches 29.810 inches; so that the former rises .013 and the latter .020 of an inch. The fall from 10 A.M. to 4 P.M. is from 29.806 inches to 29.790 inches, or .016; and that from 10 P.M. to 4 A.M. is from 29.810 to 29.793 inches, or .017. The greatest departures from mean pressure are in the fall from 10 A.M. to 4 P.M., when the mercury sank to 29.790 inches, and in the rise from 4 P.M. to 10 P.M. So that the greatest disturbances took place from ten o'clock in the forenoon to ten o'clock at night.

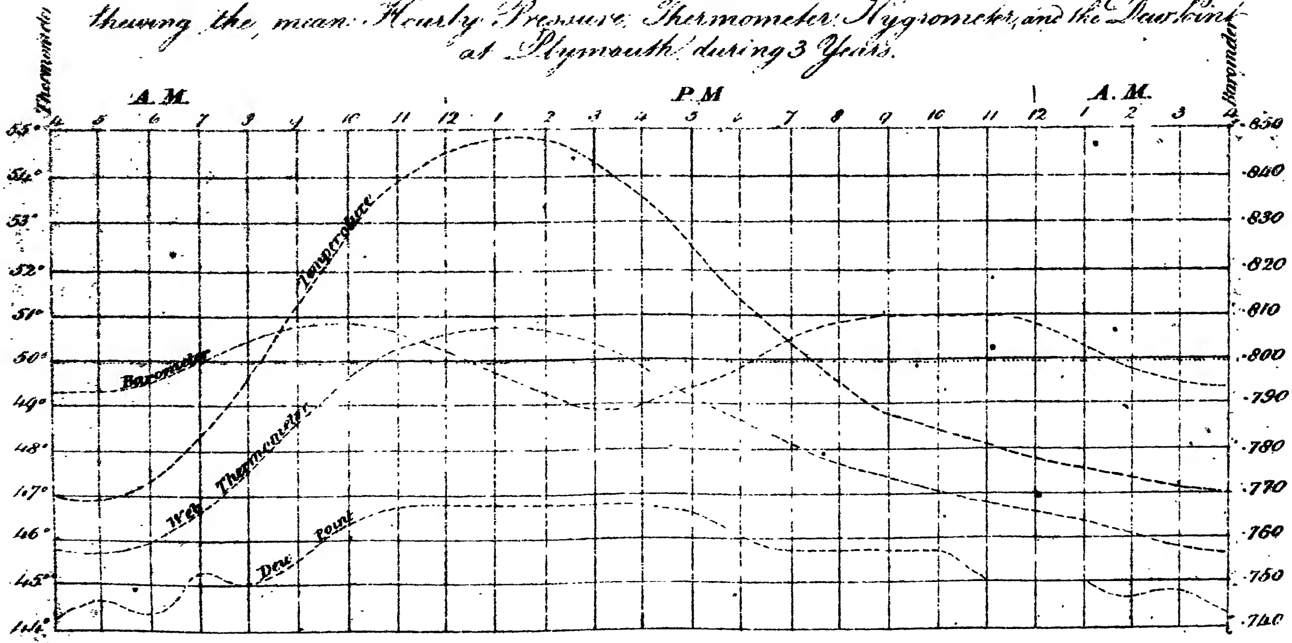
Mr. Harris speaks of each rise and fall of the barometer as shewing a tide in the atmosphere; but it is sufficiently evident that the atmospheric tides are not caused by the

* See Plate No. I.

LATE I.

DIAGRAM,

Shewing the mean Hourly Pressure, Thermometer, Hygrometer, and the Dew Point at Plymouth during 3 Years.



attraction of gravitation, as no influence of the moon can be traced in the times of their occurrence. That they are connected with the solar influence is indicated by the relation which they preserve to the daily apparent movement of the sun. Inequality of temperature in the atmosphere seems the most probable cause of the oscillations, yet the temperature produced by the sun on the surface of the earth, as measured by the thermometer, is increased during the former part of the day, and progressively diminished during the latter part, and the night, as may be seen in the thermometric curve in the diagram. This curve shews that the daily movement of temperature at the surface of the earth is as follows:—It begins to rise a little before the sun, increases until about one o'clock in the day, when it turns and declines; and continues falling until about five o'clock the next morning,—making but one rise of eight, and one fall of sixteen, in the twenty-four hours. From these facts it sufficiently appears that the two daily atmospheric tides or movements cannot be caused directly by the sun heating the surface of the earth.

By comparing the height of the wet bulb thermometer, the curve of which is given in the diagram, with that of the ordinary dry bulb thermometer, we trace the effect of evaporation in cooling that instrument. This evaporation also shews that vapour is then in the process of being formed from wet surfaces and thrown into the atmosphere; whilst the dew-point curve, which is also given, exhibits the quantity of vapour existing in the atmosphere at the time. By tracing and comparing these facts, we shall be enabled to see the nature and extent of the alterations that are going on; first, from changes in the temperature, and, secondly, from alterations in the quantities of vapour to be found in the atmosphere. And to do this we will divide the twenty-four hours into four periods, corresponding with the oscillations, as No. 1, 2, 3, and 4,—the first and third shewing the two risings, and the second and forth the two fallings of the barometer.

During the first period, from 4 to 10 A.M., the thermometer rises 6°, which expresses the rise of the temperature near the surface of the earth, whilst the wet bulb thermometer rises only 4°, shewing that evaporation had become more energetic: and the result of that greater energy of evaporation is seen in the rise of the dew-point about 2°, through the additional vapour thus thrown into the atmosphere. Now, the tendency of the increase in the temperature, which took place during this period, was to make the atmosphere lighter, and thus to cause the barometer to fall; but the additional vapour, which had been produced by evaporation, had the opposite tendency; as the increase in the pressure of the vapour against the mercury would tend to make the whole atmosphere heavier, and the barometer to rise. A local increase in the temperature of the atmospheric column of 6° would produce a fall of say .375, whilst the additional vapour furnished, as marked by a rise of 2° of the dew-point, would cause a rise of the mercury of say .024.* But we see that the barometer during the time rises .013, so that all the influence of the higher surface temperature is apparently expended in counteracting the rise of the barometer .011. From these facts it becomes evident that that increase of temperature, which is marked by a thermometer placed near the surface of the earth, produces but a small effect on the pressure of the atmosphere, as was indeed shewn when treating on the influence of surface temperature in producing sea breezes.

From 10 A.M. the mercury begins to fall, and continues falling during the second period, that is, till 4 P.M.; and we

* The forces of vapour, as given in Daniell's tables, at the dew-points exhibited in the curve, are as follows, viz.:—

at 44° — .328	of an inch	of mercury.
" 45° — .340	"	"
" 46° — .352	"	"
" 47° — .364	"	"

thus shewing that a rise of the dew-point 1° increases the force of atmospheric vapour .012 within this range of the dew-point.

have now to ascertain what are the alterations which occur in the surface temperature, and in the quantity of vapour thrown into the atmosphere, by evaporation, during this period. It is, however, desirable that we should divide it into two parts—one from 10 A.M. to 1 P.M., and the other from 1 to 4 P.M., in order that we may see more distinctly the alterations that take place.

From ten to one the surface temperature rises nearly 2°, and the dew-point rises less than 1°, which takes place from ten to eleven o'clock; but the barometer, instead of continuing to rise, as it did from 4 to 10 A.M., when the same two causes were in operation, now falls; and during these three hours falls say .010 of an inch of mercury. Thus the direction of the influence of the two causes in operation is now reversed; for, from four to ten, the rise of surface temperature 6° counteracted, to a small extent, the pressure of the additional vapour, but from ten to one, when the rise is less than 2°, it seems fully to counteract that pressure, and also to lighten the mass of the atmosphere enough to cause the mercury to fall .010.

From 1 to 4 P.M. the air cools, as the surface temperature falls, and the dew-point remains unaltered; we ought, therefore, to find the cooled air produce its full natural effect on the barometer in making it rise; for now, as the dew-point remains stationary, there is no cause in operation, yet adverted to, but the cooling of the air, which ought to make the mercury rise, but, instead of rising, it falls say .006; shewing that the causes hitherto traced as being in operation, are insufficient to account for the effect produced.

But let us take the whole of the second period, and trace the natural results of the alterations in the surface temperature, and the change of the dew-points, and compare those results with the actual movements of the mercury in the barometer. First, then, we observe, that the surface temperature at the end of this period was the same as at the beginning,

[illegible], and, therefore, the influence of temperature [illegible] the mercury at the same level at the con- [illegible] it was at the beginning of the period; [illegible] [illegible], that it had fallen .016 of an inch, whilst the dew-point had risen less than 1°, which should have produced a small rise instead of a fall of the barometer; this fall, therefore, cannot be attributed to any alteration of either surface temperature or of the quantity of vapour in the atmosphere, and we have to discover the real cause that produces the fall during this period.

The rise of the oarometer during the first period, we will presume, is attributable to the additional vapour thrown into the atmosphere by evaporation, as that is an adequate cause for the production of such a rise. But there is reason to believe that this evaporation continued during the second *period, as the difference between the temperature* marked by the wet bulb and that marked by the dry bulb thermometer proves that that evaporation was then going on. Indeed evaporation must evidently have been more active and energetic at this time than it was in the previous period, as it will be seen, by the diagram, that the wet bulb thermometer was cooled down by evaporation to a greater distance below the temperature marked by the dry thermometer than it had been previously, and, consequently, much additional vapour must have been thrown into the atmosphere. But why, then, was the weight of the atmosphere, as measured by the barometer, not increased by this additional vapour? or, rather, why did the barometer fall instead of rising? It could not be any alteration of surface temperature that caused the fall of the barometer, because we have seen that that was the same at 4 P.M. that it had been at 10 A.M.; and the necessary effect of the weight of the additional vapour that had evaporated, and passed into the air, must have been to produce a rise. Thus, these two causes tended to produce the opposite effect to that which occurred, and there must, consequently, be some other

cause sought to account for the effect produced on the barometer during the second period.

Say, then, that the additional vapour thrown into the atmosphere by evaporation, in the first period, causes a rise in the barometer, which rise was checked to some extent, by the increase of surface temperature; and the general result, by 10 A.M., was such a rise as has been shewn. But at 10 A.M. vapour continued to rise through the increase of temperature, although it disappeared, as we do not trace its existence in a further rise of the dew-point. But what became of it? It, no doubt, became condensed into small particles of water, and formed a floating or ascending cloud: and from 10 A.M. to 4 P.M., that is, during the whole of the second period, the vapour produced by evaporation was condensed into cloud, and thus was prevented from appearing in a higher dew-point. By carefully observing all the facts presented to us, first, in the temperature of the ordinary thermometer—secondly, in the state of the wet bulb thermometer—and, thirdly, in the stationary condition of the dew-point, it becomes sufficiently evident that vapour must have been freely produced during this period, and also that it must have been condensed and formed into cloud. The process here described may be seen in many parts, taking place with considerable regularity, cumulous clouds beginning to form about 10 A.M. and increasing till about 4 P.M., when the process generally ceases. Now the effect on the barometer of this additional portion of vapour thus thrown into the atmosphere, and remaining there, whether as an invisible fluid, the existence and amount of which was indicated by a higher dew-point, or as a cloud which remained suspended in the atmosphere, and added to its weight, must have been to increase the aggregate weight of the whole atmosphere pressing on the mercury of the barometer, and to cause it to rise. Yet we have seen that, during this same time, the mercury, instead of rising, fell,—and the fall was .016; we have, therefore, to seek for the

cause of this fall of the barometer in some other operation [illegible]; and that other operation is, evidently, one of which [illegible] been already said in these pages, the heating of the [illegible] of the atmosphere in the locality by the condensation of the vapour which had become cloud.

By referring to pages 13 and 115, it will be seen that the atmosphere may be heated, by the condensation of vapour, sufficiently to cause a material alteration in its weight and pressure. If the condensation should be great enough to produce rain, it may cause the barometer to fall to a considerable extent, and that fall may continue beyond the regular daily period, as has been shewn when treating of the irregular movements of the barometer. But if the condensation be only the ordinary daily result of the sun heating the surface, and causing the lower part of the atmosphere to rise, until the greater cold of the higher portion condenses some of the vapour that it contains, and forms cloud, then the fall of the barometer will measure the effect of that formation of cloud which is consequent on surface heating by the sun. If this view is correct, the surface heating, as shewn by the thermometer, acts only as an agent to raise vapour to a sufficient height to produce condensation, and the heat liberated by the condensation of the vapour is that which really makes the atmosphere light, and causes the barometer to fall. This view exhibits to us the causes of the semi-diurnal oscillations of the barometer, as not only in accordance with its alterations, as far as we have traced them, namely, from 4 A.M. to 4 P.M., but also as in harmony with the more extensive irregular fluctuations of that instrument as already explained; whereas, by supposing the semi-diurnal effects to arise from alterations of surface temperature, and of the quantities of vapour in the atmosphere, we suppose causes to determine them which are quite insufficient, and which are most palpably inadequate to account for the greater and more irregular fluctuations of the barometer.

We now reach the third period, from 4 to 10 P.M., when the mercury rises. And, by comparing the curve of the dry with that of the wet bulb thermometer, it will be seen that, during the same time, evaporation was less active; and the fall of the dew-point shews that the quantity of vapour left in the atmosphere, at the surface, was reduced. With reference, therefore, to the vapour pressing on the mercury, we ought now to have a fall of the barometer. But the barometer does not fall;—on the contrary, it rises .020, being considerably more than equal to its fall during the previous period of six hours. It is true the thermometer shews that the surface temperature fell at the same time from 54° to 48.5°; but if alteration of surface temperature influenced the previous movements so little, as it has been shewn it did, we cannot suppose that it would produce so great an effect as a rise of the barometer of .020 during these six hours. But then what can be the cause which thus counteracts the natural result of a reduction of the pressure of vapour on the barometer? Why, it may be presumed to be—evaporation of the cloud that had been previously formed; as that is not only adequate to produce all the effects, but it is a cause which, it may be shewn, must have been in operation at the time, and which, from the known laws of nature, must have produced an effect of the kind that was experienced.

When condensation in the higher regions of the atmosphere ceased at 4 P.M. a large mass of cloud was left floating there; and, from the known laws of evaporation, this mass would then begin to dissolve, and cool the air in the part; for as condensation had previously heated, expanded, and pressed away a part of the atmosphere, and reduced its weight, so evaporation would now cool and contract it, and additional air would flow from adjoining parts and make the whole mass in the locality heavier, and cause the barometer to rise. The cold resulting from evaporation of cloud would now increase the pressure of the atmosphere sufficiently, not only to

overcome the effect of the reduction of vapour pressure, as indicated by the fall of the dew-point, but also to cause the barometer to rise .020 of an inch. And thus, it is conceived, the movement of the barometer during the third period is accounted for, the cold resulting from cloud evaporation being the operating cause. It should, however, be remembered that as the cloud cooled by evaporation, it, or the air cooled by it, would descend and occupy a lower level, and either the cloud itself, or the mass of air with which it was intermingled, would reach the surface of the earth, and there spread itself into a thin stratum; as it is known the heaviest air in the part always becomes the lowest. This process causes the land breeze that is experienced in so many parts of the world, where the atmosphere is sufficiently moist to produce the daily condensation and evaporation of vapour and cloud which create fluctuations of temperature and sea and land breezes.

By 10 P.M. the effects of cloud evaporation have been experienced, and then we have the second diurnal fall, which amounts to about .017. To account for this fall we have only to look at the reduction in the quantity of vapour in the atmosphere by the formation of dew at the surface. The thermometer shews that the surface temperature was sinking at this time, which, if it produced any effect, would have caused a rise of the barometer—we see, however, that it falls. But the dew-point sinks from 45°.7 to 44°.2, which, by reducing the vapour pressure .018, produces the fall of the barometer, and this fall continues until the approaching sun, by raising the surface temperature, causes fresh evaporation, and, from 4 to 10 A.M., by producing additional vapour pressure on the barometer, causes it again to rise and commence its daily oscillations.

The accounts of the Plymouth observations have alone been brought forward, because they are the most full that have been published. *In addition to the heights of the*

barometer and thermometer, they give the registration of the wet bulb thermometer and of the dew-point; and this fulness enables us to trace the production of vapour by evaporation in the first morning period, its condensation to form cloud during the second period, its subsequent evaporation in the afternoon, the reduction in the vapour pressure during the night, and the effects of all these changes on the general atmospheric pressure. But there are accounts from other places which, although less full, may be adverted to, in order to shew that the same causes produce similar effects in other parts, though those effects differ in degree from the changes at Plymouth. Mr. Harris gives tables of the semi-diurnal oscillations of the barometer at Madras and Poona, taken from accounts furnished by Colonel Sykes. The following are these accounts tabulated with the Plymouth observations:—

At	Rise from 4 to 10 A.M.	Fall from 10 A.M. to 4 P.M.	Rise from 4 to 10 P.M.	Fall from 10 P.M. to 4 A.M.
Plymouth	.0133	.0166	.0204	.0171
Madras	.0470	.0790	.0630	.0350
Poona...........	.0445	.1116	.0884	.0181

From this table it will be seen that at Madras the vapour which, from the increase of temperature, it is presumed, rose in the morning period from four to ten, was sufficient to cause the barometer to rise .0470 of an inch of mercury; and as there is no doubt that vapour continued to rise with the rising temperature, and passed into the atmosphere at that place, such vapour would have caused a further rise of the barometer during the second period, namely, from ten to four, had there been no cause in operation to prevent it. But at Madras, as at Plymouth, about ten o'clock, a part of the vapour, doubtless, was raised sufficiently to commence the

process of condensation and to form cloud; and the formation *of that cloud heated the air in the locality* so much as, by four o'clock, to cause the barometer to sink .0790 of an inch. And be it observed, too, that, at the end of this second period, it is apparent that at Madras, as at Plymouth, the surface temperature would be about the same as at the beginning of it, and, therefore, the fall of the barometer could not be caused by an alteration of surface temperature. In like manner we may say that the dew-point would be stationary, as it was at Plymouth, whilst the additional vapour or cloud would tend to increase the weight of the whole atmosphere; but the heat liberated by condensation must have been sufficient to counteract the influence of this additional quantity of vapour, and to reduce the pressure of the atmosphere equal to .070 of an inch of mercury.

The rise during the third period at Madras, produced by the cold of cloud evaporation, was .0630, being less than the previous fall from condensation, in that respect differing somewhat from the Plymouth oscillations. In the fourth period the fall of the mercury, from the presumed disappearance of a part of the atmospheric vapour in the formation of dew on the surface of the earth, was .0350.

From an examination of that part of the table which relates to Poona, it will be seen that the great fall which occurred there, in the second period, and the rise in the third, indicate the condensation of a very large amount of vapour into cloud, and the subsequent evaporation of that cloud. Had we the wet and dry bulb thermometers, and the dew-point registered for this part, as they have been at Plymouth, we might trace their separate effects, as has been done for that place, and thus prove, more conclusively, that the alterations during the day, that is, in the second and third periods, are attributable to condensation and evaporation, and not to surface temperature and alterations in vapour

pressure. The analogy in the three cases is, however, sufficiently close, and there seems no reason to doubt that the same causes which produced the effects in one case produced them in the others.

Sir J. Herschel has furnished, in vol. 13 of the Transactions of the British Association, an account of the barometric altitudes observed at Mauritius during the twenty-four hours, containing the mean of fourteen months. In this account the heights at the turning points are—

At	4 A.M.	10 A.M.	4 P.M.	10 P.M.
INCHES. 30	.0343	.0794	.0199	.0841

And the observations, when dotted down, and the dots connected by lines, exhibit curves so similar in character to those already given, or treated of, as to indicate that similar causes were in operation in all the cases. The fall, from cloud formation, during the second period, from 10 A.M. to 4 P.M., was .0595, and the rise, from cloud evaporation, was .0642, and these constitute the departures from the line or curve, of one rise and one fall, which it is probable would be found if the causes in operation were only one rise of temperature, and one augmentation of vapour pressure in the beginning of the day, and one decline of each in the latter part of the day and the night.

In a paper presented, in 1844, to the British Association, at York, by Colonel Sabine, containing meteorological observations at Toronto and Prague, the Colonel intimated that the variations of temperature, as indicated by the thermometer near the surface of the earth, and the alterations in the quantities of aqueous vapour existing in the atmosphere, during the twenty-four hours, sufficiently accounted for the semi-diurnal oscillations of the barometer in those places. In the tables exhibited by him, the heights of

the mercury measuring atmospheric pressure, and the separate pressure of the vapour atmosphere, were given, and were as follows:—

At	4 A.M.	10 A.M.	4 P.M.	10 P.M.
Atmospheric pressure...	*29.602*	*29.634*	*29.590*	*29.608*
Vapour pressure........	*.234*	*.270*	*.279*	*.249*

But it has been shewn that, at Plymouth, during the second period, in the hottest part of the day, the dew-point did not determine the quantity of vapour that had passed into and remained in the atmosphere, in some form adding to its weight, as that dew-point was stationary, though the wet bulb thermometer shewed that evaporation had been very active. We must, therefore, presume that the pressure of vapour, or of its product cloud, in Toronto and Prague, during this period, was greater than is shewn in this table. And after one o'clock, P.M., when the quantity of vapour in the atmosphere must have been increasing, and the temperature, as at Plymouth, must have been declining, and when, therefore, from the influence of both these causes, the barometer ought to rise, we find, from the tables, that it fell,—as it ought to do if cloud formation was the cause that produced the result. It should be borne in mind, also, that Toronto and Prague have each a low mean temperature and dew-point, and the daily formation of cloud may not take place as regularly in those parts as it does in others having higher temperatures and dew-points. The semi-diurnal oscillations in these comparatively dry parts will approximate to the state of those localities where no daily cloud is formed, such as the North African desert or the plains of Eastern Patagonia. But this difference between the movements of the barometer at Toronto and say Madras and Poona, furnishes additional evidence of the truth of the theory here advanced. The semi-diurnal oscillations are, it is contended, results of daily cloud forma-

tion and evaporation, and where very little or no such formation occurs, the double oscillation will be but little or not in any degree traceable.

In some regions clouds frequently cover the earth day and night, when the morning sun cannot warm the surface sufficiently to raise the lower air, consequently a daily new cloud *cannot be formed. And as the great condensation which* often takes place in those regions produces a proportionately great ascent of air and vapour, and causes the minute particles of water which constitute cloud to form into drops, and fall to the earth as rain, instead of being suspended in the air as cloud to evaporate, much cold air, produced by cloud evaporation, cannot descend, and considerable regular daily variations of the barometer cannot then occur in the part. Mr. Birt, in his letter to Sir J. Herschel, in the volume of the British Association for 1841, says—"One point which I have glanced at in the notes appears to me interesting and worthy of attention in future observations and discussions of this kind, namely, the appearance of the diurnal oscillations, when the extent of oscillation at the station is small, for instance, under 0.1 inches. Generally, as the oscillation increases, the diurnal oscillations become obscured." This fact, not reconcilable with any other theory yet advanced, is in accordance with that now advocated.

ESSAYS

ON VARIOUS

METEOROLOGICAL SUBJECTS.

BY

THOMAS HOPKINS.

PREFACE TO THE METEOROLOGICAL ESSAYS.

Since the preceding pages were first published, various accounts have been successively furnished of Meteorological facts observed in different parts of the world. Many of these have been carefully examined, not only on account of their importance, but also in order to ascertain how far they were in harmony with the general hypothesis that has been advanced. Some of the results of such examinations have been from time to time communicated in Papers read to the Literary and Philosophical Society of Manchester; as have also certain observations which I myself had opportunities of making, together with such remarks as they seemed to require. As the subjects which had to be investigated were to a considerable extent novel, and somewhat obscure, it appeared necessary to discuss them rather minutely, and in a way that may possibly, by some persons, be thought tedious. This however appeared unavoidable, if satisfactory

reasons were to be given in each case for the conclusions arrived at.

The form of the Essay, as originally read, has been retained now that the whole are brought together; and as the various subjects were considered successively in separate Papers, and each point discussed had to be closely examined, it was scarcely possible to avoid more or less of repetition; but this circumstance, it is presumed, renders the argument more conclusive in each instance, whilst it saves the general reader the trouble of frequently referring to preceding parts.

Many of the Papers have been already published either in *The Philosophical Magazine*, *The Transactions of the Literary and Philosophical Society of Manchester*, or in *The Architect*; and are now collected, together with a few not previously published, but which, it is presumed, will assist in placing the general subject more fully before the reader.

JULY, 1853.

ESSAY I.

On the Diurnal Changes of the Aqueous portion of the Atmosphere, and their Effects on the Barometer.

The quantity of vapour existing in the atmosphere in each hour of the day is ascertained from the dew-point, it having been found that each particular quantity of vapour diffused through the air has its separate dew-point. The dew-point is therefore taken as the measure of the quantity of aqueous matter existing in the atmosphere, and of the vapour pressure, at every period of time. This pressure, thus ascertained, being deducted from the whole atmospheric pressure, furnishes the amount of the gaseous pressure, as given in our Meteorological Registers and Tables.

But, is the dew-point a correct measure of the quantity of aqueous matter that passes into and remains in the atmosphere during the different times of the day? On the answer to this question it depends whether the hourly vapour and gaseous pressures on the barometer are, or are not, correctly given in our registers. If the dew-point be a true measure, then the pressure arising from aqueous matter may be taken to be such as is stated in those registers, and so far all the reasonings respecting the causes of the diurnal fluctuations of the barometer may be correct; but if the dew-point is a fallacious measure of that pressure, then the alleged facts may be unfounded, and the conclusions drawn from them erroneous.

There is reason to believe that in certain parts of the world, where the atmosphere is very dry, the dew-point may be a

correct indicator of the pressure of aqueous matter, but in other parts it may not; and in order that we may trace this difference, in different times and places, we will inquire what are the relative quantities of vapour that hourly pass into the atmosphere, in some of those parts from which we *have been furnished with accounts, and endeavour to learn whether those quantities are such as to accord with the dew-points.*

Kaemtz, a German meteorologist, in his Course of Meteorology, has furnished tables of the hourly vapour pressure in different places, deduced, in the usual way, from the dew-point, and among them of that which is found to be the mean of the year at Appenrade, in Denmark, from seven in the morning to eleven in the evening. At seven, the pressure, in French measure, is 8.119 millimetres, from which it increases until one in the afternoon, when it reaches 9.511. From this time it diminishes, and at 11 P.M. is only 7.863.

The same writer has given the vapour pressure on the coasts of the Baltic, at Trapstow, near the Rya, for the months of July and August. It appears that in those parts the minimum pressure for July is 10.05 at two o'clock in the morning, and the maximum is 11.41 at two o'clock in the afternoon. For August, the minimum is 11.18 at three o'clock in the morning; and there are two risings, the first until ten o'clock, when it is at 12.05: from this time it falls till two, and then suddenly rises until three o'clock, from which time it falls for the rest of the day. From these statements we find that there is, on the coasts of the Baltic, particularly in August, in the middle of the day, a material departure from a single rise and a single fall in the vapour pressure.

There are also tables for Zurich, and other places in its neighbourhood. At Zurich, in the month of June, the minimum pressure is 10.56 at 4 A.M., from which hour it rises until 8 A.M. After this it falls a little, and irregularly fluctuates until 8 P.M., when it reaches 11.34, having

fluctuated greatly during twelve hours, namely, from 8 A.M. to 8 P.M., and ranged 0.78.

In September, at the same place, the minimum was at 5 A.M., and there were two risings, with an intervening fall. The first rise was up to twelve o'clock,—four hours later than the first in June; and the advance above the minimum was 1.73, making a greater range than that of June by 0.95. Here, too, the disturbance in the middle of the day is very palpable. These parts of the world are at comparatively low levels,—the first named being near the sea, and the last (at Zurich) an inland situation, which, though considerably above the sea, is not on a mountain.

When these observations were made at Zurich in the month of June, others were made on the adjoining mountain, called the Righi, 1402 metres above the Lake of Zurich. On the Righi, the minimum pressure was at 5 A.M., an hour later than that on the plain, being then 6.27, from which it rose until noon, and reached 7.54, making a range of 1.27. From this hour the pressure declined until five the next morning.

On the Faulhorn, a mountain in the same locality, but higher than the Righi by 870 metres, observations were made in September, at the same time that others were made at Zurich; and on the mountain the minimum pressure was 3.40, and occurred at 6 A.M., an hour later than at Zurich. From this time it rose until three in the afternoon, when it reached 5.07, making the range in the day as much as 1.67. It is thus shewn that the range of vapour pressure was greatest, not where the temperature was the most raised, and where evaporation must have been the greatest, but in the latest and coolest month, and on the highest mountain. And in September the pressure increased to the latest period of the day, not near the surface, the source of evaporation, but on the high mountain. These irregularities shew that some cause was in operation, which determined the vapour that had been produced by evaporation from the surface of the

earth, in the warm and comparatively dry month of June, to continue increasing at the low level up to eight in the evening, but to accumulate only to a moderate extent, whilst on the mountain it accumulated to a much greater extent, but not later than until noon. In the cooler month of September, however, the vapour accumulated to about an equal extent, and about the same times, on the low level and on the high mountain, presenting a great difference between the action of the vapour in June and in September. The absolute pressure of the vapour, it will be recollected, is greater in the lower than in the higher strata; but the increase of that pressure is greater in the higher part in the dry and warm month of June, while it is only equal in the moist and cool month of September, shewing that it was not merely expansion and diffusion of the vapour produced by evaporation that were in operation, but that some other cause was at work, which made the vapour accumulate on the mountain more than on the plain in June, but not in September.

In high latitudes the pressure of the vapour is the least in winter, and the most in summer. In Halle, in Prussian Saxony, for instance, it is 4.509 in January, and in July 11.626, almost three times the amount; and the same kind of difference between winter and summer is found in other northern parts. Generally it may be said to be the least in winter and in cold climates, and the most in summer and in warm climates.

When the daily dew-point, contiguous to the surface of the earth, is the nearest to the temperature, which is, say at four or five in the morning, both the temperature and the dew-point are the lowest. From this time the temperature rises more than the dew-point, until the former reaches the highest point for the day. There is consequently in the lower part of the atmosphere an increasing difference occurring between the temperature and the dew-point up to the time of the highest temperature. But this does not take place in

the same degree in the higher strata, as in them the dew-point progressively approximates to the temperature, until at some height the two become the same. In the forenoon, therefore, the lower air has its temperature removed progressively further from the dew-point, but when it ascends, it approaches the dew-point of the higher strata, until at last, at some height, condensation takes place and cloud is formed. When this occurs, the vapour that is in the air below the cloud, being partially relieved from incumbent vapour pressure, ascends more freely from the lower to the higher regions, where the cloud is forming. Thus it is the rise of temperature near the surface that increases evaporation and raises the dew-point, and the vapour produced by this evaporation expands and forces its way upwards by its own laws of expansion and diffusion. But in ascending it cools by expansion 1° for, say, every 500 yards, whilst it has to pass through the gaseous atmosphere, a medium which is made colder by its own law of cooling, 5° for every 500 yards of elevation; therefore, as the vapour ascends, it must at some height reach a temperature low enough to condense a part of it and form cloud. On the formation of the cloud taking place, a part of the vapour that is in the atmosphere is converted into globules of liquid (water), and the pressure of this condensed vapour on that immediately below it nearly ceases: for these globules of water, unlike the vapour from which they have been formed, do not rest upon or float in the vapour atmosphere alone, but also on the gaseous portion of the atmosphere, which, from its superior quantity and density, will sustain the greater part of the weight of this floating water. The lower vapour, relieved from a portion of that which previously pressed on it, expands upwards more rapidly, and ascends sometimes so freely as to prevent such an accumulation as shall further raise the dew-point, although evaporation continues active below. Indeed the pressure from above may be so far removed by cloud formation, and the ascent of the

vapour be rendered so free and rapid, as to lower the dew-point, as took place both at Zurich and on the coast of the Baltic. The processes which have been here described may be traced by attending at the same time to the dew-point and the heights of the ordinary and the wet bulb thermometers. These are exhibited in the Plymouth registers and diagrams, presented to the British Association by Mr. S. Harris.

By reference to these,* it may be seen that at Plymouth the difference between the dry and wet bulb thermometers is, at five in the morning, say about 1° of Fahrenheit. This difference increases until one in the afternoon, when it is, say, 4°; evaporation must therefore have gone on with increasing activity during this time; and at three o'clock, that is, two hours after the time of highest temperature, the difference between the two thermometers is greater than it was at eleven o'clock, two hours before the highest temperature. Evaporation must therefore have been more energetic, and must have continued to throw into the atmosphere more vapour from eleven to three than it had done four hours earlier. Now, if increase of vapour pressure always accompanied increase of vapour, the increase of pressure at Plymouth must have continued up to three o'clock. If, however, we look at the curve or line of the dew-point which represents vapour pressure in the diagram, we find that it did not rise after eleven o'clock, but continued stationary from that hour until 4 P.M. It is therefore apparent, that at Plymouth the quantity of vapour which by evaporation passed into the atmosphere in the middle of the day, to add to the general atmospheric pressure, in some form, was not indicated by the dew-point. And analogy authorises us to infer, that in other parts of the world, the state of the dew-point during the same portion of the day does not express the quantity of vapour that has passed into the atmosphere, and which must have added to its general pressure on the barometer.

* See also page 130 and Plate No. 1.

In the Toronto registers, reported to the British Association at York in 1844 by Colonel Sabine,* the state of the wet bulb thermometer is not given. But we may assume that if it had been given, it would have shewn the same features as those we have in the Plymouth registers and diagrams. In this report* it is, however, stated that Mr. Caldecott has transmitted to England five years of hourly observations with the wet and dry bulb thermometers at Trevandrum, near Cape Comorin, where a large quantity of vapour generally exists in the atmosphere. It appears from these accounts that the minimum and maximum pressures of the atmospheric vapour are there found to occur within three hours of each other,—the minimum coinciding with the coldest hour, 6 A.M., and the maximum occurring so early as at nine in the forenoon. Now, it is very desirable that it should be ascertained whether evaporation did or did not go on freely from the wet bulb thermometer from six in the morning, not only until nine in the morning, but until two in the afternoon, the time of the highest temperature. Although the dew-point ceased to rise at nine, it is to be presumed, reasoning from analogy, that energetic evaporation continued through the middle of the day, and it probably was (as at Plymouth) more active between nine and two in the day, than it had been in any part of the time between six and nine in the morning. And the vapour which was thus produced at Trevandrum between nine and two, or still later in the day, may have ascended and formed cloud, which cloud must have added to the general weight of the atmosphere. Had we accounts of the state of the wet and dry bulb thermometers, and of the dew-points at different heights, there is little room to doubt that we might trace the ascent of the vapour at Trevandrum until we found it collected and floating in the atmosphere as a cloud, and in that form adding to the general weight of the atmosphere.

* Which report was inserted in the February number of the Philosophical Magazine for 1845.

Colonel Sabine says that the maximum of vapour pressure occurring at Trevandrum at 9 A.M. may be a consequence of the sea breeze blowing at that time. I have however shewn that the daily sea breeze is itself produced by the diurnal cloud formation; the sea breeze is only another effect arising from the same cause. The sea breeze blows towards the part, because the atmosphere has there been made lighter than in adjoining parts by the heating power of condensing vapour. The wind too that comes from the sea, particularly in the fine season, when the diurnal disturbance of the barometer is the greatest, comes more fully loaded with vapour after nine o'clock than was the air over the land before that time, and ought to increase the vapour pressure after that hour, instead of stopping the increase. If all the vapour that arose had to come from the same land surface of the locality, it might be supposed that evaporation could not continue to supply an adequate quantity to raise the dew-point after nine; but when the sea breeze sets in, a current of air comes from an extensive sea surface, and brings with it the vapour which had been evaporated from that surface, not only up to nine o'clock, but until ten, twelve, or two o'clock, or still later: the tendency of the sea breeze is therefore not *to reduce, but to increase* the supply of vapour. It may also be remarked, that whilst the maximum of vapour pressure is said to occur at Trevandrum at nine o'clock, the sea breeze does not set in at Bombay until about eleven or half-past eleven. Supposing both these places affected alike by the sea breeze, the cause of the stoppage of increase of vapour pressure, whatever that cause may be, must have been in operation two hours before the sea breeze commenced blowing.

Formation of cloud is a cause sufficiently powerful in its operation to prevent the dew-point rising at Trevandrum after 9 A.M., as the vapour produced after that hour may be equal only to that which is consumed in cloud formation; and we

are authorised to conclude that it is to that formation we are to attribute the stoppage of the dew-point at Plymouth at eleven, and at Trevandrum at nine o'clock, instead of having it rising with the temperature during the hottest portion of the day in both places. And in the more northern or drier climates, if we do not always trace the same stoppage, it is to be attributed to the absence of daily cloud formation. In a very dry and cold climate, there is not in the course of the day sufficient water evaporated to produce a daily thick cloud, and therefore small vapour pressure goes on increasing with the temperature up to the hottest period. Under these circumstances, the vapour pressure, when exhibited in a diagram, forms a regular curve, having one rise and one fall in the twenty-four hours; but where much vapour exists, and much more is produced daily, the dew-point does not at all times indicate the pressure which results from evaporation, because the rise of the dew-point is stopped at certain periods, not by a cessation of the production of vapour, but through its ascent in the atmosphere and conversion into a floating cloud. Boiling water in the open air does not rise above 212°, yet heat continues to pass into it from the fire that is under the water. The reason that the temperature of the water does not rise higher is, that as much heat passes from the water into the air as from the fire into the water. In like manner, evaporation of water may continue to throw vapour into the air without the quantity in the air increasing, because condensation may convert vapour into water as fast as evaporation furnishes it. But neither the fire nor the vapour is annihilated,—the fire passes into the atmosphere and the vapour becomes cloud, and we may trace both of them in their new state of existence, and mark the effects they produce.

Taking the period of a year, in all places the average daily march of the temperature shews a single rise from about six in the morning till one or two in the day; and evaporation, as shewn by the wet bulb thermometer, increases with the rise

of temperature. If the whole weight of the vapour thus produced were to be registered and exhibited in the form of a curve, that curve would be the same in form as the curve of temperature, having one rise and one fall. But in the actual curve or line of the dew-point there is frequently found to be a fall where there should be a rise. At Zurich and near the Baltic, the departure from the regular curve is considerable; in Plymouth, the line is level from eleven to four; and in Trevandrum, if a curve were formed, the line would cease to rise at nine o'clock, five hours before the hottest period. At Trevandrum the minimum and maximum of the dew-point occurred within three hours, whilst on the Faulhorn they were nine hours asunder; at Zurich, in June, they were sixteen hours asunder; and in other parts similar anomalies occur. These irregularities may be accounted for on the supposition that condensation of vapour produces them, because that process is very irregular in its action; but if this supposition is admitted to be true, it will follow that the dew-point is not a correct measure of the daily addition that is made to the weight of the atmosphere in the middle of the day by the vapour that has been thrown into it, and therefore it does not present the means of ascertaining the separate gaseous pressure. For the same operation that keeps down the dew-point in the middle of the day, creates cloud that floats in and rests upon the whole mass of the atmosphere; and the gaseous portion of that atmosphere must then press on the surface of the earth, not only with its own weight, but with the additional weight of nearly the whole of the cloud that is then floating in it. And if the curve of gaseous pressure, as commonly given, does not shew a rise resulting from this additional pressure, it is because the whole atmosphere is at the same time made lighter by the heat which has been liberated by condensation of vapour.

ESSAY II.

On the Causes of the Semi-diurnal Fluctuations of the Barometer.

I have already shewn that there is no reason to believe that the daily warming of the atmospheric gases by the direct influence of the sun produces any material alteration in their pressure on the mercury of the barometer, as the effect of that warming on the whole column in the locality is so small, as to prevent much disturbance of atmospheric pressure; yet great influence has been attributed to solar heating near the surface in producing the semi-diurnal fluctuations that take place.

Colonel Sabine, in his Report on the Meteorology of Toronto at the meeting of the British Association for the advancement of Science, in 1844, gives an explanation of the daily oscillations. He says—"As the temperature of the day increases, the earth becomes warmed, and imparts heat to the air in contact with it, and causes it to ascend. The column of air over the place of observation thus warmed rises, and a portion of it diffuses itself in the higher regions of the atmosphere, where the temperature at the surface is less. Hence the statical pressure of the column is diminished. On the other hand, as the temperature falls, the column contracts, and receives in its turn a portion of air which passes over in the higher regions from spaces where a higher

temperature prevails; and thus the statical pressure is augmented."

In the Athenæum of July 5, 1845, the Colonel is represented as having said at the then recent meeting of the British Association, that in Dr. Buist's Meteorological Report from Bombay, "the explanations thereby afforded of the diurnal variations of the gaseous pressure at Bombay, which, although at first sight more complex than at the stations of Toronto, Prague, or Greenwich, he conceives to be equally traceable to variations of temperatures." Colonel Sabine, therefore, after having examined Dr. Buist's meteorological registers, retains the opinion that the semi-diurnal alterations of the gaseous pressure are produced by alterations of temperature, as that temperature is shewn by the thermometer near the surface.

As I propose to examine this theory and to compare it with another, it will be convenient to designate the two by distinct names. I shall therefore call the Colonel's "*the temperature theory*," and the other, "*the condensation theory*." Both of these rest on alterations of temperature; but the former depends on the temperature found by thermometric measurement near the earth's surface, and the latter on the temperature which must be produced by condensation of vapour in a higher part of the atmosphere, of which we have no direct measure.

The semi-diurnal fluctuations of the barometer are the greatest within the tropics; and as details of those at Bombay have not yet been published, we will proceed *to examine accounts furnished by* Kaemtz, in his valuable work on Meteorology. In page 248 of that work, we have the following tables of the hourly heights of the barometer:—

TABLE I.

Mean height of the barometer expressed in millimetres for all hours, and in different places.

Places	Gt. Ocean.	Cumana.	La Guayra.	Calcutta.	Padua.	Halle.	Abo.	Petersburg.
Latitude...	0° 0′	10° 23′ N.	10° 36′ N.	22° 35′ N.	45° 24′ N.	54° 29′ N.	60° 57′ N.	59° 66′ N.
Observers.	Horner.	Humboldt.	Boussingault.	Balfour.	Ciminello.	Kaemtz.	Hallstroem.	Kupffer.
Noon	752.35	756.57	759.41	759.61	757.02	753.29	759.31	759.47
1	751.87	755.99	758.91	759.22	756.85	753.11	759.29	
2	751.55	755.47	758.41	758.39	756.67	752.99	759.27	759.38
3	751.15	755.14	758.12	758.12	756.54	752.89	759.25	
4	751.02	754.96	758.05	757.91	756.47	752.84	759.25	759.32
5	751.31	755.14	758.10	757.93	756.46	752.86	759.27	
6	751.71	755.41	758.40	758.01	756.50	752.91	759.29	759.31
7	751.93	755.81	758.90	758.02	756.63	753.02	759.34	
8	752.35	756.21	759.19	758.54	756.79	753.14	759.39	759.32
9	752.74	756.59	759.69	759.24	756.92	753.24	759.44	
10	752.85	756.87	759.93	759.33	757.02	753.31	759.47	759.36
11	752.86	757.15	759.98	759.09	757.02	753.29	759.47	
Midnight	752.47	756.86	759.64	758.80	757.01	753.23	759.41	759.35
13	752.20	756.53	759.34	758.62	756.90	753.14	759.33	
14	751.77	756.21	759.05	758.57	756.84	753.05	759.24	759.32
15	751.63	755.89	758.81	758.49	756.78	752.99	759.14	
16	751.32	755.66	758.68	758.47	756.74	752.99	759.07	759.32
17	751.65	755.79	758.85	758.44	756.75	753.34	759.03	
18	751.95	756.18	759.32	758.68	756.79	753.12	759.04	759.39
19	752.84	758.58	759.94	759.16	756.89	753.24	759.08	
20	752.95	756.98	760.50	759.88	757.01	753.37	759.15	759.49
21	753.16	757.31	759.63	760.11	757.08	753.44	759.21	
22	753.15	757.32	760.50	759.19	757.14	753.46	759.29	759.51
23	752.80	757.01	759.99	759.09	757.07	753.40	759.32	

From an examination of this table, it will be seen that the fluctuations are the greatest within the tropics, and they diminish, though not invariably, with the increase of latititude.

The first column exhibits the fluctuations at the equator in the great ocean. The range extends beyond two millimetres, and the descent from nine in the the morning till four in the afternoon gives the whole extent of the range.

The two next columns shew the alterations at Cumana and La Guayra, both above 10° north latitude, and the ranges are nearly equal to that at the equator.

The fourth column shews the changes at Calcutta to be nearly as great as in the preceding places, but exhibits singu-

In the Padua column, 45° north, the fluctuation is much reduced in the extent of its range, but retains the same general character.

In Halle, in latitude 54°, the alterations do not differ materially from those at Padua.

The changes are very small in Abo and Petersburg.

To these it is desirable that we should add the following table of the heights of the dry and wet bulb thermometers, and the differences between the two,—with the dew-points and the heights of the barometer at Plymouth for three years, as furnished by Mr. S. Harris, and published in the Ninth Report of the British Association (p. 167).

TABLE II.

Table of the heights of the dry and wet bulb thermometers, and the differences between the two, together with the dew-points and heights of the barometer at Plymouth for three years.

Hour.	Thermometer.	Wet bulb thermometer.	Difference.	Dew-point.	Barometer.
1 A.M.	47.52	46.20	1.32	45.00	29.8017
2	47.33	46.03	1.30	44.75	29.7993
3	47.11	45.92	1.19	44.75	29.7944
4	47.00	45.66	1.34	44.25	29.7928
5	46.98	45.77	1.21	44.75	29.7928
6	47.41	46.01	1.40	44.50	29.7960
7	48.44	46.83	1.61	45.25	29.8002
8	49.68	47.51	2.17	45.00	29.8032
9	51.30	48.50	2.80	45.26	29.8048
10	52.84	49.45	3.39	46.25	29.8061
11	53.00	50.02	3.88	46.75	29.8045
12	54.51	50.40	4.14	46.75	29.8002
1 P.M.	54.83	50.55	4.28	46.75	29.7957
2	54.77	50.44	4.33	46.75	29.7922
3	54.25	50.24	4.01	46.75	29.7908
4	53.45	49.80	3.65	46.75	29.7895
5	52.27	49.06	3.21	46.25	29.7938
6	51.24	48.46	2.78	46.00	29.7970
7	50.28	47.90	2.38	45.75	29.8019
8	49.44	47.51	1.93	45.75	29.8061
9	48.83	47.17	1.66	45.60	29.8[illegible]4
10	48.48	46.93	1.55	45.60	29.8099
11	48.10	46.66	1.44	45.00	29.8092
12	47.80	46.43	1.37	45.00	29.8065
Mean ...	50.32	47.89	2.43	45.60	29.7999

In all these places the temperature shews only a single fluctuation, such as is seen in the table of the thermometer at Plymouth, namely, one rise generally from about 5 A.M. to 1 or 2 P.M., and one fall from that time until five the following morning. Now, if the temperature of the atmosphere, as marked by the thermometer, caused the diurnal fluctuations of the barometer in the way supposed, we ought to have in all these places one undulation in the twenty-four hours instead of two,—the rise of temperature causing a decline of the barometer during the hotter part of the day, and the fall of temperature producing a rise of the barometer in the colder part. Yet Colonel Sabine himself says that at Bombay, where there is only one rise and one fall of temperature, there are two risings and two fallings of the barometer. And these movements of the barometer take place not only when that instrument is taken as the measure of the whole pressure of the atmosphere, but also when the vapour pressure is deducted, and the mercury of the barometer is taken as the measure of the gaseous pressure alone. These facts are opposed to, and are irreconcileable with, the temperature theory.

As, however, the aqueous vapour of the atmosphere presses on the mercury of the barometer separately and independently, it has been attempted to be shewn that the variable pressure of the vapour arising from difference in the quantities in the atmosphere at different periods of the day combined with change of the gaseous pressure resulting from alteration of surface temperature, and that the two causes acting together produced the double undulation of the barometer; to this view, therefore, we will direct our attention.

The temperature near the surface of the earth at Plymouth, as well as at the other places, rises from about five in the morning till about two in the afternoon; and when the wet bulb, as well as the dry thermometer, is used, as it was at Plymouth, it is seen that the temperature of the latter

rises more than that of the former, or of the dew-point, and evaporation must consequently become progressively more active; there must therefore be successively more water evaporated and thrown into the atmosphere to be added to its weight. And according to the temperature theory, this water, now converted into vapour, must, up to say ten o'clock, press with sufficient force on the mercury to counteract the lightening influence of the rising temperature, as during that time the barometer rises.

From ten until one o'clock, as the temperature rises still higher, as compared with the wet bulb thermometer and the dew-point, evaporation must go on increasing, and the increase of vapour pressure ought to continue; but it appears from the table not to do so, as the mercury of the barometer falls instead of continuing to rise; we have therefore to try to ascertain what can be the cause of this fall, while additional vapour is passing into the atmosphere.

Those who advance the temperature theory, say that the fall of the barometer is caused by the increasing temperature of the atmosphere produced by the action of the sun on the surface of the earth, and the air near to it; and they must maintain that this increase is sufficient, not only to lighten the atmosphere enough to cause the fall of the barometer, but also in addition to counteract the influence of the increased vapour pressure. Now at Plymouth the temperature rises from 5 to 10 A.M. nearly 6°, and may be supposed to lighten the atmosphere to a certain extent; at the same time evaporation throws vapour into the atmosphere. We are, however, required to suppose that during this time the vapour produces so much greater effect by pressing on the mercury, than the heating of the atmosphere does in reducing atmospheric pressure, that the whole pressure becomes greater and the mercury rises. But after ten o'clock the temperature continues to rise, but in a smaller degree, say nearly 3°, and vapour must be more abundantly thrown into the air, as is

shewn by the extent to which the wet bulb thermometer is kept down; yet the barometer, instead of continuing to rise, suddenly turns and falls, and continues falling from ten to one o'clock, the time of the highest temperature. So that according to this theory, from five to ten o'clock, the sun heats the air nearly 6° and produces some vapour; and the two influences acting together cause the barometer to rise; but from ten to one the sun heats the air about 3°, and must throw much additional vapour into the atmosphere; and then these two influences still acting together cause the barometer to fall. This is attributing opposite effects to the same causes, and must be presumed to be erroneous.

But let us examine the valuable Plymouth tables a little more minutely. The first column gives the temperature as shewn by the ordinary thermometer; the second, the temperature of the wet bulb thermometer, as kept down by the cooling influence of evaporation; and the third gives the difference between the two first. Now as this difference arises from the extent of the evaporation, the numbers of the difference may be taken to express the force and amount of evaporation, and to indicate the additional vapour that is discharged into the atmosphere. This force or amount at five o'clock in the morning is 1°.21, from which time it increases to 3°.39 at ten o'clock. So that during these five hours, the increase in the force of evaporation is 2.°18; and this in the temperature theory must be held to be sufficient to overcome the lightening effect of a rise of 5°.86 of temperature, and also to raise the mercury of the barometer to the full extent of the morning rise. After this time, from ten to one o'clock, the temperature rises further from 52°.84 to 54°.83, or 1°.99; and during the same period the force of evaporation increases .89, that is, from 3°.39 to 4°.28. Thus we are required to believe, that from five to ten in the morning, 2°.18 of evaporation overcame the lightening influence of 5°.86 of temperature, and in addition raised the mercury of the barometer; and from

ten to one in the day, .89 of evaporation not only failed to overcome the lightening effect of 1°.99 of temperature, but allowed this relatively small amount of temperature to produce the further result of a fall of the mercury of the barometer. Or put in a tabular form, say that from

5 to 10 o'clock, 5°.86 of temperature and 2°.18 of evaporation caused a rise.
10 to 1 o'clock, 1°.99 of temperature and .89 of evaporation caused a fall.

That is, where temperature, the influence which lightens the atmosphere, is relatively great and should cause a fall, the mercury of the barometer rises; and where the influence of temperature is relatively small and should cause the vapour to produce a rise, the mercury falls. This must be erroneous.

In the same place, (at Plymouth,) from 1 o'clock until 4 P.M., as may be seen in the table, the temperature falls; and as far as *that* temperature acted the atmosphere would of course become heavier. At the same time evaporation shews that vapour is passing into the atmosphere; it ought therefore to follow that the barometer should rise, and considerably too, through the operation at the same time of both the causes which are supposed to contribute to the production of a rise. But the barometer does not rise; on the contrary, it falls, and continues falling until four o'clock. These facts and reasonings prove that neither the daily variations of surface temperature, nor the different amounts of vapour pressure, nor both taken together, are adequate to the production of the fall of the barometer from ten to four o'clock in the day.

And if we proceed with our inquiries into the next period of six hours, that is, from 4 to 10 P.M., we meet with facts that do not harmonize with the temperature theory. During the whole of this time, it is true, the temperature falls and the barometer rises: but the vapour pressure must have diminished according to the temperature theory, as the dew-point, the measure of vapour pressure, falls; and the lowering

of the dew-point after four o'clock shewed that vapour was then condensing in the lower part of the atmosphere. So that here it becomes necessary to suppose that the atmosphere cools enough, not only to raise the barometer to the full extent of its daily range, but also to counteract the reduction which takes place at the same time in the vapour pressure. Again, from ten at night, although the atmosphere continued to cool, the barometer did not continue to rise, but once more fell, which fall is attributed to a diminution of vapour pressure. Thus from four to ten in the afternoon and evening, cooling the atmosphere is represented as more powerful than reduction of vapour pressure; and from ten in the evening to four in the morning, reduction of vapour pressure is supposed to be more powerful than cooling the atmosphere. The two forces, we are required to believe, do not merely neutralize each other, but each in its turn exercises a paramount influence, and for the time determines an absolute rise or a fall of the barometer; and this we are called upon to admit without any satisfactory or even plausible evidence being adduced to prove it.

What has been here advanced applies with the greatest force to the semi-diurnal fluctuations in atmospheric pressure which take place within the tropics. Aqueous vapour exists in the atmosphere in larger proportions in that part of the world than it does in higher latitudes; and it is to the daily condensation of that vapour in the atmosphere, and its subsequent evaporation there, that we are really to attribute the great deviation of the movements of atmospheric pressure from the daily march of temperature. If no vapour existed in the atmosphere, the alteration of pressure would be very little, and it would be the reverse of temperature. As the atmosphere became warmer, the pressure would be less; as it became colder, the pressure would be more. And the hourly variation in the quantities of vapour actually found

in the atmosphere which arises from alteration of surface temperature, only introduces another element of pressure into the inquiry, which is simple in its character,—the vapour increasing or diminishing with an increase or diminution of temperature. If the two were equal while acting in opposite directions, they would balance each other. But the separate action of these two causes cannot produce such a double undulation of the mercury of the barometer as that which occurs daily in the tropical regions and at Plymouth.

As we proceed from the equator towards higher latitudes, we find less vapour in the atmosphere, and its influence on atmospheric pressure is less marked. At Padua the fall of the barometer from ten to four in the day is not much more than one-fourth the extent that it is at the equator, and at St. Petersburg it is very small. In situations where there is not sufficient vapour in the atmosphere to form any daily cloud, it is to be presumed that if a barometrical registration were to be made, there would be no double movement exhibited shewing a fall from 10 A.M. to 4 P.M., and a rise from 4 to 10 P.M., because there would be no condensation and warming to produce the former, nor evaporation and cooling to cause the latter.

The heating effect of condensing vapour may however be traced even in comparatively dry latitudes, such as that of Toronto, as shewn in Colonel Sabine's report to the British Association in 1844. There was no fall of the barometer at that place from four to ten in the morning, although the temperature had risen from 39°.20 to 46°.35, above 7°; but in the middle of the day, from ten to four, with an increase of temperature from 46°.35 to 50°.55, being only 4°.20, the gaseous as well as the general atmospheric pressure was materially reduced, notwithstanding that the increase in the quantity of vapour during this time must have been as great

as it was in the preceding period; and if this increased quantity had remained in the atmosphere, its pressure must have been added to that which previously existed. We are then obliged to suppose that the reduction of the pressure which took place immediately after ten o'clock, arose from a cause which came into operation at that time; and that cause it is contended can be found only in the heating of the atmosphere by the condensation of vapour.

The great defect of the temperature theory is, that it fails to account for the fall of the barometer from 10 A.M. to 4 P.M., and its subsequent rise from 4 to 10 P.M., though this is the oscillation for which we have particularly to account; whilst the theory here maintained points out the cause of these, as well as the other diurnal, and also of the casual, movements of the barometer. We are therefore at liberty to conclude that the semi-diurnal fluctuations of the barometer can be accounted for only on the condensation theory.

ESSAY III.

On the Times of the Daily Atmospheric and Barometric Disturbances at Bombay.

That the daily fluctuations of the barometer in many parts of the world are connected with the changes of winds called sea and land breezes, is generally admitted. Some persons consider the winds the causes of the barometric alterations, whilst others treat the phenomena as joint effects resulting from the same common cause; these winds, however, have seldom been examined with a view of shewing to what extent they coincided with the movements of the barometer. But it is desirable that this should be done, as any anomalies in the daily movements of the barometer, and in the times when the sea and land breezes blow, may direct attention to causes which, without having been noticed, may, to a greater or less extent, determine each of these phenomena.

A sufficient number of facts has been collected to enable us to shew, that the sea and land breezes do not blow at the times when it would be expected that they should, through alterations that are taking place in the atmosphere, as such alterations are indicated by the movements of the barometer. These breezes are said to blow invariably from a part where the atmosphere is relatively heavy, to another part where it is lighter; we ought, therefore, to find, that wherever the sea breeze was blowing with increasing strength, the atmosphere on the land towards which it was blowing, was becoming lighter, and the barometer on the land was falling. In like manner when the land wind was blowing with increasing force,

the atmosphere must be supposed to be increasing in weight over the land, which increase should be measured by a rise of the barometer on the land.

If, however, the movements of the barometer do not accord with the times of these winds, but that instrument sometimes rises when, from the direction of the wind, it should fall, and the reverse,—we have to ask why this should occur? There must be some sufficient cause in operation to produce these effects, so different from what is expected from the nature of the influences supposed to produce them, and into the nature of this cause we ought to inquire.

The combined influence of temperature, as shewn by the thermometer, and of variable vapour pressure, as ascertained by the dew-point, have been supposed sufficient to account for both the daily changes of the wind and of the barometer. But I have shewn that the dew-point is not a correct measure of the quantities of aqueous matter that exist in the atmosphere during the different periods of the day; although there can be no doubt that those quantities do vary, and, in many parts of the world, probably to a greater extent than has been hitherto imagined, though the aqueous matter is not always in the form of vapour.

Alternating sea and land breezes are, doubtless, effects of the disturbance of the equilibrium of atmospheric pressure. The air passes from the place where the pressure is greater towards the part where it is less, and this passage of the air constitutes the wind. In the important account of the Meteorology of Bombay, furnished to the British Association at Cambridge, by Colonel Sabine, it is stated, that "the land wind declines till about 10 o'clock A.M., at which time the direction of the aërial current changes, and there is generally a lull of an hour, or an hour and a half's duration. The sea breeze then sets in, the ripple on the surface of the water indicating its commencement, being first observed close in shore, and extending itself gradually out to sea. The sea

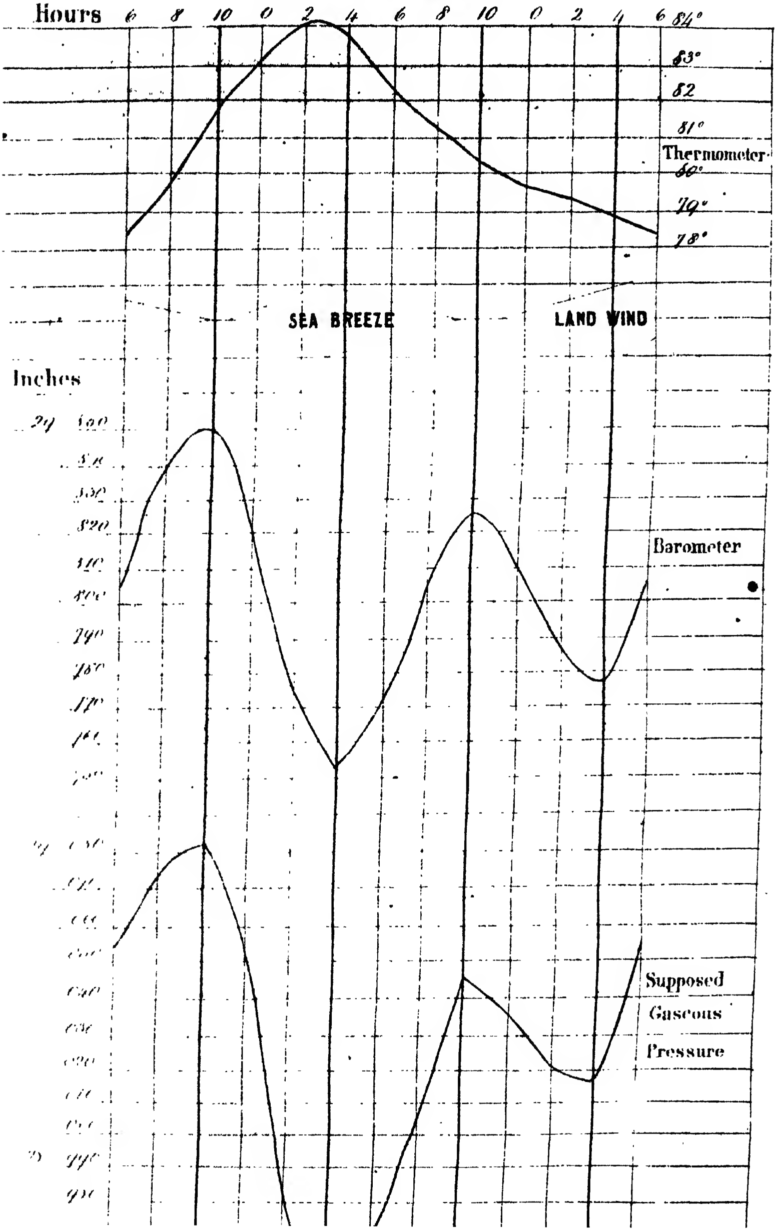
breeze is freshest from two to four, and progressively declines in the evening hours."

According to this, as well as other accounts which need not at present be given, we may, then, say that soon after ten o'clock in the morning, some cause comes into operation that makes atmospheric pressure less over the land than it is over the sea, and therefore a portion of the air flows from the sea to the land,—from where the pressure is greater to where it is less. This disturbance of the equilibrium of atmospheric pressure has been represented as arising from the sun heating the surface of the land more than that of the sea. But if this were the cause in the case just given, the sea breeze ought to have set in earlier, seeing that the thermometer at Bombay, near the surface of the earth, rose much more before half-past ten o'clock in the morning, than it did after that time. From six in the morning the temperature rose from 78°.4 until at ten it reached 81°.8, and at twelve 83°.2. So that at ten it had risen 3°.4, and at twelve 4°.8, whilst after that period until two it rose only .9, or to 84°.1. The rise of temperature was therefore far greater before the sea breeze set in, at half-past ten, than it was afterwards, and the sea breeze ought to have commenced long before half-past ten o'clock to have been in accordance with the times of the change of temperature.

The following table, taken from Colonel Sabine's paper, shews the heights of the thermometer and the barometer, and the supposed separate gaseous pressure every two hours. The same facts are also exhibited in the diagram, together with the changes of winds.

* See Plate No. 2.

of the Semi-diurnal alterations of the
THERMOMETER, WIND BAROMETER, & SUPPOSED GASEOUS PRESSURE.
AT BOMBAY.



Hours of Mean Bombay Time.	Thermometer.	Barometer.	Supposed Gaseous Pressure.
6	78°.4	29.805	29.055
8	79°.6	—.840	29.074
10	81°.8	—.852	29.081
0	83°.2	—.817	29.049
2	84°.1	—.776	28.981
4	83°.9	—.755	28.955
6	82°.3	—.774	28.972
8	81°.2	—.806	29.005
10	80°.3	—.825	29.045
0	79°.8	—.809	29.034
2	79°.4	—.786	29.020
4	78°.9	—.778	29.017

The highest temperature, 84°.1, is found at two o'clock, after which time it declines a little till four, when it is at 83°.9;—and if high temperature, as measured by the thermometer, really produced the sea breeze, it should have increased in strength until two, when as the temperature declined, the breeze should also decline. But the sea breeze is found the strongest from two to near four o'clock. The sea breeze, therefore, is of inferior strength up to two o'clock, when it ought to be the strongest, and it is the strongest when it should, according to the temperature theory, have become weaker.

At four, although the atmosphere, as shewn by the thermometer, had become colder than it was at two o'clock by .2, yet it was then in its lightest state, as measured by the barometer, shewing that the temperature and weight of the atmosphere were not in harmony with each other. After four the barometer begins to rise, and the sea breeze to weaken; and these alterations proceed until near ten at night, when they cease.

At this time the air over the land is found to be heavier than that over the sea, as the aërial current turns and begins to flow from the land to the sea,—or the land breeze sets in.

It is feeble at first, but increases in strength until it reaches its maximum near day break, say between four and five o'clock, during which time the temperature declines. While, however, the land breeze is thus blowing with increasing strength, and indicating by its force that the atmosphere is becoming considerably heavier over the land, the barometer, which should be the measure of increase of atmospheric weight, does not rise as from theory would be confidently expected, but actually falls. And that this fall of the barometer is not attributable to a rise of thermometric temperature, as that of the morning has been supposed to have been, is evident, because the thermometer was sinking during the whole time. That the fall of the barometer is not due to a general reduction of atmospheric pressure may also be reasonably inferred, seeing that the land breeze indicates an increase of that pressure over the land, from whence the air is by some cause forced to flow towards the sea. What then can make the air go with increasing velocity from a part where the atmospheric pressure, as that pressure is measured by the barometer, is successively becoming less and less? Or rather, we may ask, what can cause this fall of the barometer on the land, when, from the action of the land wind, the air over the land appears to be increasing in weight? These questions, it would seem, cannot be satisfactorily answered on the temperature theory, and yet they require to be answered, if we are to understand the causes that are in operation to produce the various results that have been traced.

From what has been stated, it will have been seen that after ten o'clock in the morning, some cause comes into action, sufficiently powerful to reduce atmospheric pressure on the land, and to render the air there so light as to permit the sea air to flow towards the land as the sea breeze. This cause, I contend, is not to be found in the warming of the surface of the land by the sun, as has been supposed,—but in the conversion of a part of the aqueous vapour of the atmosphere

into water by the formation of cloud, as I have shewn in my account of the formation of cumulous cloud. A consequence of this conversion is the liberation of heat, which lightens the whole atmospheric column in the locality. The results are, a fall of the barometer over the land, and a flowing in of the heavier air from the sea as the sea breeze. The formation of cloud, on an average, continues in operation until four o'clock in the afternoon, during the whole of which time the barometer falls, and the sea breeze blows with increasing force. At four o'clock cloud ceases to form,—the barometer then ceases to fall, and soon begins to rise, whilst the sea breeze becomes weaker, until about ten o'clock in the evening, when the barometer attains its greatest evening height, and the sea breeze ceases to blow.

During the six hours last named, from four to ten o'clock, that the atmosphere over the land becomes heavier than it had previously been, is indicated both by the rise of the barometer and the decline of the sea breeze. But it is here contended that these results are produced, not merely through that reduction of temperature which is marked by the fall of the thermometer, but in addition, and principally, through the cooling of a large mass of the atmosphere by cloud evaporation. From ten in the morning to four in the afternoon, a portion of the vapour over the land had been condensed and formed into cloud; and the heat liberated by that condensation rendered the land atmosphere lighter at the time: but now, from four to ten at night, the particles of water which constitute the cloud evaporate—and as condensation previously heated the land atmosphere, and made it lighter, so evaporation now cools it and makes it heavier. The former process caused the barometer to sink, and the sea breeze to blow—the latter causes the barometer to rise, first checks, and finally stops the sea breeze. Cloud formation in the former period produced so great an effect as to counteract the influence of increasing vapour pressure, which may be shewn to have

existed at the time, and in addition to lower the barometer and produce the sea breeze; and cloud evaporation had, in the latter period, sufficient power to overcome the influence of declining vapour pressure, which was going on at the time in the formation of dew near the surface, and to produce the general results that have been stated.

At ten at night, the air over the land is found to be, principally through the influence of cloud evaporation in cooling the column, heavier than it is over the sea—the atmospheric current now turns, and the air begins to flow from the land to the sea—or the land breeze sets in. It is feeble at first, but increases in strength, until at day break, or about four or five o'clock, it reaches its maximum. While, however, the land breeze is thus blowing from eleven at night to four in the morning, and seeming to indicate that the air is becoming heavier over the land, the barometer on the land at Bombay is not rising, as might be expected, but on the contrary is falling. Now, that this fall is not attributable to an increase of temperature is clear, as during the time the thermometer is sinking. And that it is not due to a general diminution of atmospheric pressure is to be presumed, because the land breeze shews that that pressure is increasing over the land. What, then, is the cause of this fall of the barometer? It is, apparently, the reduction, not of general atmospheric pressure, but of separate vapour pressure through the deposition of dew.

From ten at night to five in the morning, the period now under consideration, radiation of heat cools the surface of the earth, and that part of the atmosphere which is near to it, sufficiently to condense a part of its vapour, without thereby raising the temperature, as the cooling effect of radiation is greater than the heating influence of condensation of vapour, and the results are the deposition of dew and the reduction of vapour pressure without an increase of temperature. It is, then, the reduced pressure of vapour, and not any diminution

of gaseous pressure, which we presume causes the barometer to fall during the time last named. The land wind blows at the same time; because in the absence of the sun the gaseous part of the atmosphere continues to cool over the land, and the land gases press on the lighter sea gases, and flow from the land towards the sea, constituting the land wind, which increases in strength with the cooling of the gases over the land up to about sunrise.

Here, then, we see why—when, from the increasing strength of the land wind, we should expect that the barometer would rise—it falls. We see that the fall of that instrument is a consequence of reduced vapour pressure alone, whilst the reduction of that pressure does not prevent the colder gases over the land from flowing as a land wind towards the sea, where the atmospheric gases are warmer.

The approach of the morning sun prevents further cooling, and his rise soon begins to warm the atmosphere; the land breeze then diminishes in strength, until about ten o'clock, when it ceases. But from five to ten in the morning, whilst the land breeze is declining through an increase of general temperature, and a consequent reduction of gaseous pressure over the land, the barometer is not sinking, as might be expected, but it is, on the contrary, rising. Whence, then, comes the force that is now raising the barometer? It is from the increased pressure of the additional vapour which, during this time, is produced by evaporation from the surface of the earth. As the temperature rises in the morning, evaporation becomes more active, and additional vapour is thrown into the atmospheric space, which adds to the vapour pressure. Thus, while one constituent of the atmosphere in the locality is increasing in quantity, and adding to the aggregate pressure, other constituent portions, through a rise of temperature, are pressing with diminished force on the surface, exhibiting to us at the same time the apparent contradiction of a rising barometer, and an alteration of

wind that shews a diminishing atmospheric pressure. These phenomena are, however, the natural results of the independent action of the different aëriform substances that constitute the atmosphere.

Each of these constituents exists in the atmospheric space as an independent elastic fluid, the upper part of which presses on the lower, the weight of the whole resting on the surface of the globe. When aqueous vapour, one of these, is increased in quantity by evaporation, its pressure is increased, and the whole of the vapour presses on the surface with greater force: and a column of mercury exposed to this pressure rises to an extent that is proportioned to the increase. *But at the same time that this is going on, the gases, the other constituents of the atmosphere, may become warmer and lighter in the part. And it is this lightening of the gases in the morning*, that first reduces the strength of the land wind, and finally stops it, whilst the barometer is rising from an increase of vapour pressure.

The independent actions of the constituents of the atmosphere from four to ten in the afternoon, though the same in their nature as those in the morning, are differently combined. During this time, cloud evaporation over the land cools the gases, and makes them heavier, and vapour pressure must be increased by cloud evaporation, whilst the small condensation of aqueous vapour that is taking place near the surface in the formation of dew, is tending to make the atmosphere lighter, but the two former are the more powerful influences, and the barometer rises. Yet, while this rise is going on, the sea breeze is declining, because the cooling of the gases is making them heavier over the land. But after ten at night, cold ceases to be produced by cloud evaporation, and no more vapour is furnished by that process, whilst the reduction of vapour pressure by the deposition of dew continues. The reduction of vapour pressure has now superior influence on the barometer, and it falls from ten in the evening to four in

the morning, although, during this time, the gaseous atmosphere must be becoming heavier, from the decline of temperature. The influence of the cooler, and therefore heavier, land gases, is seen in the increasing force of the land wind, which, up to four or five o'clock, becomes successively stronger, while the barometer is falling.

It may be further observed, that the gaseous atmosphere is, in the temperature theory, supposed to be at its mean pressure at Bombay, about one o'clock in the day, as that is the time when the barometer is at its mean elevation, and, therefore, when the atmosphere in the locality ought to be in a state of equilibrium, and at rest; but instead of being at rest, the sea breeze is then found blowing freely, and with increasing strength. At about four in the morning, the gaseous pressure is represented as being again at the mean, but at both these times wind is blowing strongly. Now, if the theory were correct from which separate gaseous pressure is deduced, we should have a calm when the pressure was at the mean; whereas, at the times which have been pointed out, of the computed mean, decided winds were blowing.

And when the air at ten in the morning is found calm, we ought to presume, from the existence of that fact, that an equilibrium of gaseous pressure is established, such equilibrium being the necessary accompaniment of a calm. But the separate gaseous pressure, as that pressure is deduced from the dew-point, is very much above the mean, seeing that it is at the highest that it attains in the twenty-four hours.

In like manner, at ten o'clock at night, when the gases are at rest, and when therefore they must be supposed to be under the influence of a mean pressure,—the amount of that pressure as deduced from the theory, though not so great as it was in the morning, is represented as being much above the mean. These facts present strong evidence that

the method of ascertaining the separate gaseous pressure at present recognized cannot be a correct one.

We have already seen reason to believe that the barometer attains its greatest height in the morning through increased vapour pressure. And it is to be presumed from the stillness of the air at the time, that the gases were then really in a state of equilibrium; it will therefore follow, that at ten in the morning, the barometer was raised above its mean height, solely by the force of increased vapour pressure. And at night, there is another calm, when the barometric height is considerable, approaching that of the morning, and this pressure above the mean must in like manner be presumed to result, not solely from the cooling of the atmosphere, but in addition from the abundant vapour that had been recently furnished by cloud evaporation. The general conclusion to be drawn from all these facts, being, that when the atmosphere is in a state of equilibrium, any rise of the barometer above the mean level for the locality, climate, and season must be produced by increased vapour pressure.

Thus we find, that we have only to trace the effects of the various changes of temperature, arising from the different causes that are known to be in operation, on the separate constituents of the atmosphere, to perceive with considerable *clearness, how all those alterations* in atmospheric pressure, and changes of wind, which appear at the first view so incompatible and contradictory, are accomplished. The constituents of the atmosphere, separately, and independently, obey the laws which govern them, and although in so doing they may impinge upon, and to some small extent disturb each other in their movements, yet the daily fluctuations of temperature, which are the primary disturbing causes, are sufficiently slow to allow each elastic fluid to act nearly in conformity with its own laws. When vapour is, by the slow process of evaporation, discharged into the atmosphere, it

penetrates the atmospheric mass, ascends, and also expands laterally, yet rests on the surface of the globe with its own weight alone, that weight being increased or diminished as the vapour becomes more or less in quantity. But, in spreading laterally, the vapour has not sufficient force to impinge upon, and carry along the gases,—it therefore does not, in a direct and mechanical way, produce a wind. Variations in the temperature of the gases, however those variations may be produced, are the great causes of winds, both irregular and periodical; and these variations may be combined with an increase or decrease of vapour, in such ways as shall create atmospheric currents, and at the same time affect the barometer in such different modes, as to produce all those various and complicated phenomena that have, hitherto, baffled inquirers on the subject.

ESSAY IV.

Observations on a Paper entitled "Some Points in the Meteorology of Bombay," read by Colonel Sabine *to the British Association in* 1845, *and published in the Philosophical Magazine for January,* 1846.

That mere alterations of thermometric temperature near the surface and of vapour pressure, either jointly or separately, do not produce the fall of the barometer from ten o'clock in the morning to four in the afternoon, may be proved by facts when the registration of the wet bulb thermometer is given; but unfortunately this is seldom done. In the Plymouth report by Mr. S. Harris that registration is to be found; and there it may be seen that the temperature theory does not harmonize with the facts. But in the account of the meteorology of Bombay, as given by Colonel Sabine, there is no notice of that instrument. Vapour pressure, *as ascertained by the dew-point,* is there exhibited as one of the two causes which determine barometric fluctuation,—thermometric temperature *being considered the other; and these two causes are by him* represented as sufficient to account for the facts, and form the basis of his theory, which for convenient reference I have called "the temperature theory."

In remarking at present on the Bombay report, I propose to confine myself principally to objections to the theory advanced to account for the phenomena, and do not intend to shew in a detailed form what were the real causes in operation, seeing that all the facts required are not furnished. Had an account of the evaporation that took place been given, I would have attempted to trace the vapour that was produced after ten o'clock, until it was condensed in the

higher part of the atmosphere and converted into cloud, with the effects of that conversion on the barometer; but without the registration of the wet bulb thermometer this cannot be satisfactorily done.

In the report the facts contained in the following table are given for Bombay in 1843,—of mean temperature, mean barometric pressure, mean tension of vapour, and mean gaseous pressure at every second hour.

Hour of Mean Bombay Time. Astronomical reckoning.	Temperature.	Barometer.	Dew-point, or Tension of Vapour.	Gaseous Pressure.
		in.	in.	in.
16	78.9	29.778	0.761	29.017
18	78.4	29.805	0.750	29.055
20	79.6	29.840	0.766	29.074
22	81.8	29.852	0.771	29.081
0	83.2	29.817	0.768	29.049
2	84.1	29.776	0.795	28.981
4	83.9	29.755	0.800	28.955
6	82.3	29.774	0.802	28.972
8	81.2	29.806	0.801	29.005
10	80.3	29.825	0.780	29.045
12	79.8	29.809	0.775	29.034
14	79.4	29.786	0.766	29.020

This table commences at four o'clock in the morning, that hour being generally one of the turning-points in the semi-diurnal movements of the barometer. From four to ten that instrument rises from 29.778 to 29.852 inches. Now this rise, on the temperature theory, must be considered to have been produced either by a reduction of temperature, as measured by the thermometer near the surface of the earth, or by an increase of the pressure of aqueous vapour, as ascertained by the dew-point; or by both those influences acting together, and producing the rise of the barometer, as a general result.

We find, however, that during the first two hours, that is, from four to six o'clock, the thermometer fell from 78°.9 to

78°.4, being a fall of .5; and the tendency of this fall most undoubtedly was to produce a rise of the barometer; but at the same time the pressure of vapour, as indicated by the dew-point, declined so much as from .761 to .750, or .011. Now this comparatively large reduction of vapour pressure is evidently the greater of the two disturbing forces, and the result of the action of both the forces, according to the theory, ought to be a fall of the barometer. But instead of falling, the barometer rose during the two hours from 29.778 to 29.805, or .027; shewing that the movement of that instrument in this time was the reverse of what would have occurred if the temperature theory were true.

From six to ten o'clock, the remainder of the first period of six hours, the barometer continued rising, and passed from 29.805 to 29.852, making a rise in these four hours of .047, whilst the thermometer rose from 78°.4 to 81°.8, or 3°.4, and the dew-point increased from .750 to .771, or .021. Thus of the whole six hours we find that, during the first two,—

a fall of temperature of 5
and a fall of the dew-point of .011 } produced a rise of the barometer of } .027

which would appear to prove, and as far as the facts given go, do prove, that the small fall of temperature had the greater influence on atmospheric pressure, as the barometer rose .027 while both influences were in operation.

But in the following four hours, from six to ten o'clock, a rise of the thermometer of 3°.4 and a rise of the dew-point of .021, were accompanied by a rise of the barometer of .047; or put into tabular form, say that—

a rise of temperature of 3°.4
and of the dew-point of .021 } produced a rise of the barometer of } .047

that is, between four and six o'clock, when the fall of the dew-point is great compared with the fall of temperature, and the two acting together ought to produce a fall of the barometer, that instrument rises. But between six and ten

the temperature increases greatly, as much as nearly seven times the amount that it previously fell, whilst the dew-point, although it also rises, does not rise to quite double the extent that it fell in the two hours; yet notwithstanding these great alterations, amounting to complete reversals of the two influences that are in operation, the barometer continues to rise, and attains an increase of .047. These facts, however, taken together, shew that temperature, as measured by the thermometer near the surface of the earth, produces little comparative effect on the amount of atmospheric pressure; and that the alteration of vapour pressure must have had much greater influence than alteration of temperature as measured by the thermometer, and must have produced the rise of the barometer from six to ten o'clock.

Proceeding to the next six-hour stage of the daily fluctuations of the barometer, we find that from ten to two o'clock, the first four of these six hours, temperature advances 2°.3, and reaches its highest point for the day at the last-named hour; and the dew-point, indicating vapour pressure, also rises as much as .024. Here it appears that vapour pressure increases so much as .024, whilst temperature advances only 2°.3; alteration of vapour pressure therefore should, in accordance with what had occurred previously, be now more powerful than alteration of temperature, and should further increase the whole atmospheric pressure, and cause the barometer to rise higher than the point it had previously reached, as the theory we are examining teaches it ought to do; but instead of rising the barometer falls no less than .076; so that from six to ten o'clock, whilst—

a rise of temperature of	3°.4	jointly produced a rise of the barometer of.........	.047
and a rise of the dew-point of	.021		

in the following four hours, from ten to two o'clock,—

a rise of temperature of	2°.3	produced a fall of the barometer of	.076
and a rise of the dew-point of	.024		

Thus, where the vapour pressure is relatively weak, we see that the barometer rises; and where it is relatively strong the barometer sinks,—being the reverse of that which must have taken place if the temperature theory were correct.

Again, from 2 to 4 o'clock P.M. the temperature sank .2, and the dew-point rose .005. Thus during these two hours the alterations which took place in both the temperature and the dew-point were such as from the operation of each of their influences ought, on the temperature theory, to have caused the barometer to rise. But it did not rise; on the contrary it fell,—no less than .021. These facts prove most conclusively, that the fluctuations of the barometer in the times named were not produced by alterations of temperature and of vapour pressure, as they are exhibited to us by the *thermometer and the dew-point.*

It should be borne in mind, that it is the fall of the barometer from ten in the morning to four in the afternoon, while evaporation, as shewn by the wet bulb thermometer, is active, for which we have particularly to account. Temperature rises while vapour augments up to ten o'clock in the morning, and at the same time the barometer rises; but after ten, though the same two causes continue in operation, the barometer falls, and continues falling until four in the afternoon. Now why should the same causes be supposed to produce one effect up to ten o'clock, and another, of an opposite character, for six hours after that time? That is the question which has to be answered. The temperature theory, so far from accounting for the occurrence of these phenomena, is directly opposed to them, and utterly fails to account for the fall of the barometer from ten to four o'clock.

The alterations which took place in the subsequent twelve hours present additional evidence of the inadequacy of the temperature theory to account for the semi-diurnal fluctuations of the barometer; but as they are not equally palpable with those already examined, it is unneccessary to go into a consideration of them.

In furnishing such accounts as those of the meteorology of Bombay, that which is required in order more fully to elucidate the subject is, that in addition to the usual registrations the temperature of the wet bulb thermometer should be given. This would enable us to trace the vapour that is thrown by evaporation into the atmosphere in the hottest part of the day. Could we do this, there seems no doubt that it would be found ascending in the atmosphere until it became condensed and formed cloud; and the heat liberated by this condensation, as I have elsewhere explained, is the real cause of the diminished pressure of the atmosphere in the locality during the six hours that the barometer falls.

In a note appended to the paper published in the *Philosophical Magazine* for January, 1846, Colonel Sabine gives an extract from a paper received from M. Dove, which is stated to have been read in the Academy at Berlin, in which it is said that "at Catherinenbourg and Nertchinsk, on the mean of several years, and at Barnaoul, in the years 1838 and 1840, the mean diurnal barometric curve itself exhibits but one maximum and one minimum in the twenty-four hours; the maximum coinciding nearly with the coldest and the minimum with the hottest hour of the day." But the Colonel afterwards shews from other accounts, that there is a very small morning maximum in the locality named, which occurs between the hours of 8 and 11 A.M. This he attributes to the pressure of additional aqueous vapour, and he seems to think such a fact confirmatory of the correctness of his views. If however an increase of vapour up to eleven o'clock could raise the barometer, why should not that instrument rise further after that hour? Had we a registration of the wet and dry bulb thermometers, and of the dew-point, it is to be presumed that proof would be furnished that evaporation was more active after eleven than it had been before that hour, and that there was no decline of the dew-point until a much later period of the day. The vapour that must be presumed to

have passed into the atmosphere in the hottest part of the day, must either have added to the previous pressure on the barometer and raised it, or it must have been condensed, and warmed the higher part of the atmosphere. As it did not produce the former effect, in the absence of information we may assume that it produced the latter.

In the extract given from M. Dove's communication we have no account of the daily range of the barometer, or of the extent of its fall during the day, though that is the most interesting fact to be ascertained. This is to be regretted. If a sun-heated surface is the cause of the atmosphere becoming so much lighter in the day than it is in the night, the atmosphere at the places named by M. Dove ought to be rendered much *lighter every day than it was in the previous night*, seeing that the temperature of the day is raised greatly above that of the night; the daily range of the barometer should consequently, on the Colonel's theory, be extensive. Is it so? If it is not, it is so far evidence against the theory.

It is stated in the Russian account, that in the places pointed out there is one maximum and one minimum, the maximum nearly coinciding with the coldest, and the minimum with the hottest hours of the day. And the conclusion drawn seems to be, that alteration of surface temperature is the sole cause of the movement of the barometer: hence the desirableness of shewing the extent of that movement. If it be great, it will so far shew that the heating of the surface of the earth by the sun could materially diminish atmospheric pressure. But if the daily movement of the barometer is found to be small, it will present presumptive evidence that daily surface-heating has no important local effect on the weight of the atmosphere. A full account of the registrations in this part of the world might furnish the means of proving either the correctness or the fallacious nature of the temperature theory, to which objections have been here advanced.

ESSAY VI.

On the Hourly Alterations of the Vapour Atmosphere at Bombay.

I have already availed myself of the observations made at Bombay under the superintendence of Dr. Buist, through a paper on the meteorology of that place by Colonel Sabine. But since those remarks were written, I have had transmitted to me, through the kindness of Colonel Sykes, a lithographed copy of the observations themselves, in which are to be found important facts connected with the hourly production of aqueous vapour at Bombay, and its apparent influence on the movements of the barometer.

In addition to the hourly registrations of other meteorological instruments, Dr. Buist has furnished columns of the heights of the wet and dry bulb thermometers, shewing the hourly depression of the wet below the dry thermometer for each month of the year 1843. From these columns, it appears that the wet was depressed below the dry instrument, to a certain extent varying both with the time of the day and the season of the year. The depression was the least in the wet season and the greatest in the dry one; and, with reference to the diurnal changes, the depression was generally, but not uniformly, the least about sun-rise and the greatest near to mid-day. These depressions of the wet below the dry thermometer are known to be results of the cooling power of evaporation of water on the bulb of the wet instrument; and the cooling thus produced is proportioned to the extent of evaporation of water that takes place; being small when the

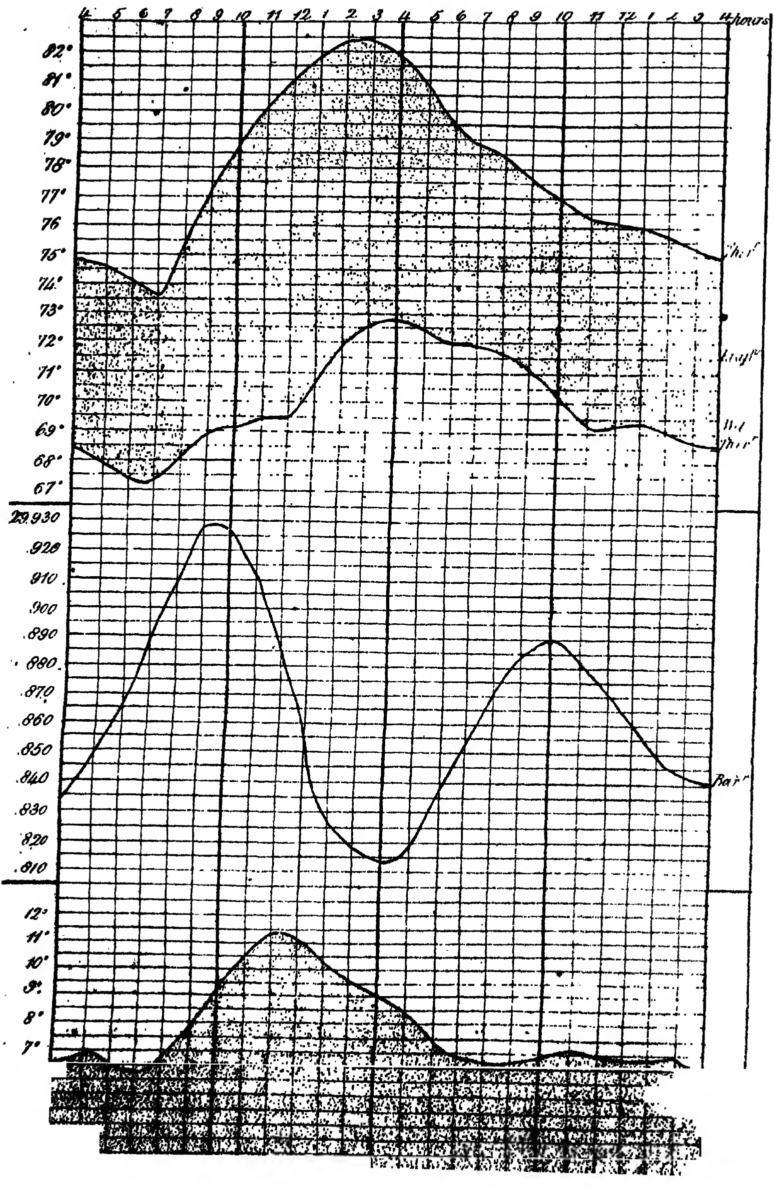
evaporation is little, and great when it is much. Thus the registration of the wet bulb thermometer not only furnishes us with means of determining how far evaporation kept down the temperature of the thermometer exposed to its influence, but also of ascertaining what were the relative amounts of water evaporated during the different portions of the time,—the cooling being the effect of the conversion of certain quantities of water into aqueous vapour, and being in every separate part of that time proportioned to the quantity converted.

We have also in a separate column of Dr. Buist's returns, the difference between the dry and the wet thermometers; and this difference may be taken to express the relative quantities of water evaporated, and the force of evaporation. From about six in the morning, varying with the season, this difference generally increases until, say twelve or one o'clock in the day, when it declines until the following morning.

As already stated, evaporation is less in the wet than in the dry season; and there is also less difference between the morning and mid-day force of evaporation in the former than in the latter season. The cold part of the year is the period for the land and sea breezes, and also for the extensive daily fluctuations of the barometer; and Dr. Buist says that this season lasts five months, namely, during October, November, December, January, and February, forming the winter of the part. But of these October is wavering and uncertain; we may therefore consider the other four months as the season when the sea and land breezes blow in the most decided manner, and in which the greatest daily fluctuations of the barometer take place; it is consequently desirable that we should carefully examine the returns for the whole of these months. To do this, we will take the mean hourly difference between the dry and wet thermometers for each month, and by adding them together and dividing by four, obtain the mean hourly force of evaporation for the winter season. This I have done, and the result is given in the following table, to

Diagram

Of the hourly heights of the Barometer, the dry Thermometer the wet Bulb Thermometer, and the relative amounts of the force of



which are added in other columns the mean hourly heights of the barometer, thermometer, and wet bulb thermometer, for the same period, that the whole may be seen at one view in juxtaposition. The same facts are shewn in a diagram,* in which the curve of the wet bulb thermometer is exhibited in accordance with the figures of the table; and also as a base line, from which the distance of the dry thermometer is shewn, the intermediate space marking the relative force of evaporation in each hour of the day.

Table of the Mean Hourly state of the following instruments, and of the force of evaporation for the four winter months of 1843.

Hours.	Barometer.	Thermometer.	Wet bulb Thermometer.	Evaporation.
4 A.M.	29.838	74°.9	68°.4	6°.5
5	29.848	74.6	67.8	6.8
6	29.867	74.1	67.4	6.7
7	29.889	73.6	67.3	6.3
8	29.911	74.9	68.1	6.8
9	29.928	77.0	68.9	8.1
10	29.928	78.4	69.1	9.3
11	29.911	79.6	69.4	10.2
12	29.884	80.8	69.5	11.3
1 P.M.	29.853	81.6	70.4	11.2
2	29.827	82.2	71.9	10.3
3	29.817	82.2	72.6	9.6
4	29.815	81.9	72.8	9.1
5	29.817	81.0	72.4	8.6
6	29.835	79.6	72.2	7.4
7	29.854	78.8	71.9	6.9
8	29.874	78.4	71.6	6.8
9	29.886	77.7	70.9	6.8
10	29.887	76.9	69.8	7.1
11	29.881	76.4	69.2	7.2
12	29.873	76.1	69.0	7.1
1 A.M.	29.862	76.0	69.2	6.8
2	29.848	75.7	68.9	6.8
3	29.841	75.3	68.5	6.8

By examining this table, we may see that evaporation at four in the morning is 6°.5, from which it rises, until at ten o'clock it is 9°.3, being an increase of 2°.8; and during this

* Plate 3.

time the barometer is admitted to be raised to the height that it attains, 29.928 inches, through the pressure of the vapour that has been recently produced by evaporation and thrown into the atmosphere.

From ten to twelve o'clock, evaporation, as measured by the difference between the two thermometers, increases up to 11°.3, being a further rise of 2°; but at the same time the barometer, instead of rising higher, as might be expected, falls no less than .044, as by that hour it sinks to 29.884 inches.

Evaporation becomes rather less active after twelve o'clock; but it still shews great force, and continues to exhibit it till four o'clock, at which time it is 9°.1, being only .2 less than it was at ten in the morning. Yet during the whole of the time from ten in the morning to four in the afternoon, when evaporation was so energetic, the barometer was falling, and sank no less than .113. What, then, became of the vapour that was produced and discharged into the atmosphere within this period? The quantity passed into the atmosphere in the six hours must have been large, it being the product of an average evaporation of 10°.3 for the whole time; whilst the average for the previous six hours was only 7°.3 when the barometer was rising. Now, can it be supposed that a comparatively small additional quantity of vapour raised the barometer considerably from four to ten in the morning, and that a further large addition to that quantity, acting in the same way from ten to four in the afternoon, not only ceased to raise it, but was attended by a fall of that instrument, to an extent greater than the previous rise,—without some other cause coming into operation? It cannot be maintained that the increase of surface thermometric temperature had but little counteracting effect before ten, and great counteracting effect after that time until four o'clock. For the rise of the thermometer from four to ten in the morning was little less than it was from ten in the morning to two in the afternoon,—

the time of the highest temperature,—it having risen as much as 3°.5 in the former, and only 3°.8 in the latter period. And it should be remembered that evaporation from ten to four was constantly adding fresh vapour to that which was previously in the atmosphere, where the whole was accumulating, and pressing with its aggregate weight on the barometer. There is, therefore, in the facts presented to us in the tables, no countenance for the supposition that temperature, as measured by the thermometer near the surface of the earth, counteracted the increase of vapour pressure after ten o'clock, and caused the fall of the barometer.

It is however sufficiently evident, from the facts given, that the vapour produced in the morning constituted the material which supplied the heat that at this time rendered the atmosphere warm and light in the locality, and caused the barometer to fall.

When the sun advances above the horizon, it warms the surface of the globe, and not only increases evaporation of water, but heats that portion of the atmospheric gases that is near the surface,—which portion rises probably in separate streams or columns,—cooler columns at the same time descending to the surface and taking the place of the warmer. This process goes on as the sun rises higher, until at some particular time, depending on the locality and season, the ascending columns reach a height sufficient to enable the expanding gases to cool and condense some of the vapour which is intermingled with them. This ordinarily takes place from nine to eleven o'clock, or say at ten in the morning, from which hour condensation is warming the atmospheric mass in the locality. This warmed mass, a mixture of gases and vapour, as it ascends, is acted on by the different laws of cooling, of condensation, and of expansion by heat, which the constituent parts of the atmosphere obey; and the result is the formation of a buoyant column of cloud, of greater or less thickness, according to the quantity of vapour that has

been condensed. The whole local column being thus made lighter by the liberated heat, it presses with less force on the surface of the earth, and consequently on the barometer. This diminished pressure is however effected through the liberated heat driving a portion of the material of the atmosphere, the gases, from the heated part to other parts of the atmospheric space; and thus we find that the heat just liberated by the condensation of vapour counteracts the increased pressure of the aqueous matter, which is at the same time passing into the atmosphere in the form of vapour. For it is here contended that the vapour that had been produced from four to ten in the morning, is, soon after the last-named hour, not only raised but condensed,—deprived of a part of its heat, and converted into minute particles of water, which float in the gaseous atmosphere as a cloud; and as such, undoubtedly form a part of the whole atmosphere and contribute to its weight. It is not therefore through a reduction in the quantity of aqueous matter in the local atmosphere, at this period of the day, that the barometer falls; but that fall is caused by the expanding power of liberated heat driving from the heated vertical column a part of the ponderable gases which previously existed within it, and, in that way, by removing a part of the material of the atmosphere, causing the remainder to press with less weight on the barometer.

The quantity of vapour that passes daily into the atmosphere while the temperature is rising, and which does not fall as rain, is returned to the earth as dew on its surface; and thus an equilibrium is established between the production and the condensation of vapour; but this does not take place during the period of which we have been treating, that is to say, from four o'clock in the morning to four in the afternoon. Vapour is not daily abstracted from the atmosphere by the formation of dew on the surface of the earth, until the barometer ceases to fall at four o'clock in the afternoon. At present we have to consider the influence of vapour during two periods of six

hours each,—that in which the barometer is rising from four to ten in the morning, and that in which it is sinking from ten to four in the afternoon: and it has been shewn that aqueous matter during the whole of this time was increasing in quantity and accumulating in the atmosphere; and as far as that matter influenced the atmosphere, it must have increased its weight. The aggregate pressure of aqueous matter did not cease to increase at ten o'clock in the morning, when the barometer began to fall; that fall was produced by a new cause which then came into operation in the locality, namely, the expanding and displacing power of liberated heat.

It will probably be asked, whether cloud forms near to, or over Bombay, after ten o'clock, and increases till four, as assumed? and to this inquiry I cannot give an answer that is likely to be quite satisfactory, not having full information on the subject. Dr. Buist, in his introductory remarks, does not particularly notice the formation of clouds within that portion of the day. In the hourly-observation tables there is a column for describing the appearance of clouds; and the entries in that column shew that the cumulus, the cirro-cumulus, and the cirro-stratus were often formed, but they are not described in such a way as would justify me in adducing them as proofs of the agency here ascribed to them, although they do furnish rather strong presumptive evidence on the subject.

Clouds are said to form pretty freely from ten in the morning till four in the afternoon, whilst from ten at night to four in the morning the atmosphere is represented as being generally clear: and taking the accounts given of the clouds during the two periods, we are fully authorised to say that they formed and remained suspended in the air during the former period, and were dissolved before the arrival of the latter period; shewing that there was daily

formation of cloud by condensation of vapour, and daily dissipation of those clouds by evaporation.

But in addition to the daily formation of visible clouds, there are indications that condensation takes place, but only to such an extent as to produce a haziness or misty appearance in the sky; and if this process is carried on until a considerable height is attained, it must warm the atmospheric mass and lighten it. Indeed, at the commencement of the process of gradual condensation, the cloud that is thereby formed is not seen; as it is only when a sufficient stratum of floating globules of water is produced that the cloud becomes visible. The first slight falling of the barometer before rain is probably caused in this way.

Judging from analogous cases, it may be presumed that palpable daily clouds at Bombay were first formed near the high ground to the east of that place, as such clouds in other similar places generally form near to, or against the sides of hills. Our old navigators have described such formations in many parts of the world; but the following account given by Hutchison of Glasgow, contains a description of that which ordinarily takes place in localities similar to that of Bombay, although the distance of the mountains from the places of observation in the two cases, and the influence of the trade-winds, may modify the process. Mr. Hutchison says that "the formation of clouds is finely illustrated by the phænomena daily exhibited during the dry season over what are called the Liguana, or Port Royal Mountains, in the island of Jamaica. These mountains are situated about four or five miles to the north-east by east of Kingston, the principal port in the island, and their height above the level of the sea is about 4000 to 5000 feet. During the dry season, from the beginning of November till the middle of April, the sea and land breezes alternately succeed each other with an intermediate interval of atmospheric stillness, in the following manner. From sun-rise

till about ten o'clock in the forenoon it is usually perfectly calm. About ten o'clock, the sea breeze, blowing at Kingston from the east, or a little to the south of east, commences and continues till about half-past three in the afternoon, when it gradually and entirely subsides." Again,—"About eleven o'clock every forenoon, or between that and mid-day, the summits of the Port Royal Mountains begin to be covered with clouds, which, though thin, fleecy, and transparent at first, gradually increase in density till about one o'clock. By this time the upper portions of the mountain, when viewed from Kingston, seem to be wholly enveloped in dense clouds, rain is apparently falling in torrents, flashes of lightning are seen, and the sound of distant thunder is heard. About half-past two o'clock in the afternoon, the clouds, gradually diminishing in density, begin to quit the mountains; so that their summits again become visible, as in the morning, and so continue till about eleven o'clock the following day. The clouds, after quitting the mountains, rise gradually to a greater altitude, and float very slowly westward, assuming as they proceed the appearance of large heaped-up cumuli."*

The general trade-wind about Jamaica was from the east, and it bore the ascending clouds to the west in the afternoon: the trade-wind at Bombay was ordinarily from north of west, and it would doubtless modify the influence of the mountains on the clouds formed in the part. Were meteorological instruments corresponding with those kept at Bombay placed to the east of that place at the rise of the hills, and registered in the same way as at Bombay, it would probably throw further light on the daily atmospheric disturbances in this part of the world, and enable us to form a better judgment of the alterations which take place in other parts. The daily range of the barometer at Poonah, which is on the eastern side of the

* See Hutchison on Meteorological Phænomena, p. 64.

ridge of the Ghauts, and far from the sea, is about as great as it is at Bombay. There can be no sea breeze at Poonah, as the mountain range is between it and the sea; but are there not diurnal winds of similar character to those on the coast? Corresponding registrations at Poonah, Bombay, and some intervening place on the west of the Ghauts, might furnish valuable additions to our stock of meteorological information, and enable us to trace the operating causes as they pass from one meridian to another, and might thus furnish us with more conclusive evidence of the nature and causes of the hourly alterations which occur in the atmosphere than any that can be adduced at present.

ESSAY VII.

On the Formation of Dew.

The nature of Dew and the mode of its formation have long engaged the attention of inquirers, and many speculations and opinions have been advanced respecting it. It is common to speak of the rising of the dew—some parties maintaining that it rises from the earth. Others have contended that it falls from the sky; and this latter view is countenanced by the common way of speaking of falling dew. A paragraph lately appeared in the public newspapers, stating that "a French savant has recently published two letters to prove that dew does not arise from the earth, or fall from the sky, but is formed by the elastic and invisible vapour diffused throughout space, which surrounds bodies."

The labours of Dr. Dalton, Wells, and others, have thrown much light on the nature of dew; but the attention recently bestowed on meteorology, and the large mass of facts accumulated relating to it, may possibly enable us to obtain a more full view of the phenomena attending the formation of dew than had been previously presented.

Those who were of opinion that dew rose from the earth, did not maintain that it came thence in the form of globules of water, as it is seen by us, but that the aëriform material of which it is constituted was supplied directly from the earth. And those who asserted that the dew fell, assumed that it was formed from vapour at some height in the atmosphere, whence it descended to the surface of the earth. Thus the idea, that dew is formed from "the elastic and invisible vapour" of the atmosphere, advanced by the French savant, is an old one—

the different opinions which then existed having reference merely to the manner in which the liquid dew was formed from the vapour.

In this, as in many other cases, disputes appear to have arisen from the same word having been used to express different ideas. The word dew is sometimes used to express the drops of water on the leaves of grass, as, in speaking of the "dew on the grass," meaning the drops of water that under certain circumstances are found on grass. At other times it is meant to convey the idea we have of the small globules of water that float in the air near to the ground, and then the word is synonymous with "low mist;" whilst it is occasionally spoken of as the aëriform material from which both the drops and globules are formed, and is then used to designate the aqueous vapour itself.

Dew and mist are formed from the aqueous vapour that exists in the atmosphere, by a degree of cold that is sufficient to produce condensation of a part of the vapour. The two names designate, not different substances, but the same substance produced in different ways. Dew has, therefore, to be *distinguished from mist only* by the mode and place of its formation, and the shape in which it exists.

Heat is found to leave all substances by radiation. In the middle of the day, under ordinary circumstances, the radiant heat received from the sun more than counterbalances the loss of heat radiated from the earth; but as the radiated solar heat diminishes on the approach of night, terrestrial radiation continues, and reduces the earth's temperature. And when the temperature of the earth and the air that is near to it are thus reduced below the point of condensation, or the dew-point, a part of the aqueous vapour of the atmosphere close to the surface of the earth is condensed, and forms particles of water so minute as to be sustained by the atmosphere, and may therefore be called mist or "floating dew." As, in the absence of the sun, the cooling influence of terrestrial

radiation increases, more vapour is condensed, and the condensation takes place at a greater distance from the earth's surface. This extension of condensation may seem to an observer to be a rising of the dew, because it will appear successively at greater distances from the surface; yet the floating globules may not really have risen, but, from the operation of the causes just pointed out, may have been all formed in the part in which they are seen, the apparent rising of the dew being a deception. Wherever aqueous vapour is condensed into water, heat is liberated, and this liberated heat may possibly expand the air in the locality sufficiently to cause it to ascend and carry the floating dew with it to a greater height. In this way the dew may really rise, if a sufficient amount of heat be liberated. When the dew extends to a moderate height it is generally called mist, and may frequently be seen filling our valleys, and at a distance looking like water.

What is called "falling dew" may be often felt in the evenings in this part of the world. But it is very common in the latter end of summer and in autumn in calm weather, and appears to be produced in the following way. During the hotter part of the day, and until about four o'clock in the afternoon, the heat of the sun raises vapour to the higher part of the atmosphere, and forms cumuli or day-clouds. Soon after this time these day-clouds begin to evaporate, and consequently to cool the atmosphere in the part. The portion of the atmosphere thus cooled is thereby made heavier than adjoining portions at the same height not similarly affected—the previous equilibrium of atmospheric pressure is then destroyed, and the cooled part sinks to a lower level. As evaporation of the cloud proceeds greater cold is produced, and by the time that the whole of the cloud is evaporated, the mass of air is so much cooled as frequently to become heavy enough to sink to the surface of the earth, where it constitutes the cold air that is often felt in the evenings

succeeding warm days in the summer and autumn;—in some places known as the land breeze. When the day-cloud is very large, the atmospheric mass is sometimes sufficiently cooled to cause it to descend to the surface of the earth, before the globules of the water constituting the cloud are all evaporated. These globules are then found floating in the lower air, and any object passing through them is soon wetted by them as if by rain, though they do not, like drops of rain, fall freely to the ground. In Lancashire, in the month of September, the clouds raised daily from the Irish Sea frequently descend in the evening to the earth, and they are abundant over the lower levels, particularly on the river Mersey, where they are well known to boatmen under the common appellation of "falling dew," and are remarkable for their intense cold, the effect of previous evaporation of a portion of the cloud in the higher part of the atmosphere. As these masses of floating particles of water are formed in the higher part of the atmosphere, they are in their origin clouds, though called floating dew when they reach a low level. It is obvious that either the floating dew formed near the surface, or this "falling dew," if carried along by a light breeze, will impinge upon, and attach to, any projecting object. In like manner, persons passing through a mass of this nature, come in contact with the globules and are wetted by them, as is well known to coachmen, boatmen, and other persons similarly exposed.

But dew also forms on objects by a process differing from those just named, and this dew is found attached to different substances in very unequal quantities. The daily clouds are often evaporated early in the evening, and the sky left clear, yet highly charged with transparent aqueous vapour. At such times, radiation of heat cools the surface of the earth until its temperature sinks below the dew-point of the atmosphere, when that part of the vapour which is in contact with the earth is condensed into water, and becomes liquid dew.

As the earth is successively cooled by radiation below the dew-point of the air, more dew is deposited, until in this way a considerable part of the vapour of the lower portion of the atmosphere may be abstracted from it, and collected on the surface in the form of water.

A French chemist, C. A. Prieur, has maintained,* "that the moisture deposited on bodies soon after sunset is not the same with that we find on them again at sunrise. There is consequently (he says) an interruption in the phenomenon—an evaporation of the serein or evening dew, and a new production in the morning, rosée."

It has been shown that what is called evening dew is often descended cloud, and it is commonly found only for a short time after the sun has set, as it soon evaporates or is deposited. The cold, too, produced by the evaporation of the cloud, ceases in a short time to be experienced, and a period then occurs, comparatively warm, when evaporation from the surface may be renewed. But, in the absence of cloud, radiation cools the surface, and acts with increasing effect upon it until some time before sunrise, when the surface is cooled to the greatest extent by radiation, and much dew is deposited. But morning—thus separated from evening—dew, by the time of its formation, is produced by the cooling influence of radiation from the surface of the earth; whilst the falling evening dew is descended cloud brought down by the cold of cloud evaporation.

The circumstances favourable to the formation of dew, are, an abundance of aqueous vapour in the air, and a clear sky. The dew-point over the Mediterranean is sometimes as high as 75°, and the transparent vapour of the part so circumstanced will, by diffusion, and the action of gentle breezes, be conveyed to the adjoining countries, where clear skies and great radiation condense large portions of the

vapour as dew, which supplies to a considerable extent the place of rain in supporting vegetation.*

It is well known that heat radiates from the surfaces of all substances, but more freely from some than from others. That which radiates from the surface of the earth, when the atmosphere is clear, seems to pass into space, and is lost to our planet; such radiation, therefore, cools the surface of the earth on a clear night. But on a cloudy night, the clouds may return nearly as much heat to the earth as the earth radiates, leaving the temperature almost undisturbed from that cause. Indeed, it is conceivable that at times the radiation from the cloud may be even greater than that from the earth. A newly formed cloud is warmer than dry air at the same height, and the radiation from the cloud is proportioned to the temperature; it is therefore conceivable that the earth may be cooled down to a low degree, and then a warm cloud be formed over it, when an excess of radiation from the cloud would warm the earth. But, whatever may be the temperature of the cloud, it will radiate heat downward in proportion to that temperature, and counteract to a greater or less extent the cooling effect of radiation from the surface of the earth: whilst in a clear sky there is no such return of heat, and therefore in such a sky radiation cools the earth's surface.

On the earth being thus cooled to a temperature below the dew-point of the atmosphere, a part of the atmospheric vapour that rests on the earth will be condensed and form dew, as already described. But it is found that this dew

* Thus, in a work entitled *Adventures in the Lybian Desert*, it is stated that—"In the Oasis of Siwah it is certain that there were heavy falls of dew during our short stay. At sunrise the thermometer generally stood at about 64°, rising to 92°, 95°, and 105°, a little after noon." And Boussingault says—"In very hot countries it is rare to be out in a cleared spot, when the night is favourable to radiation, without hearing drops of water, produced by the copiousness of the dew, falling from the trees. I have never had occasion to see more copious dews than those which occasionally fall in the steppes of St. Martin, to the east of the Eastern Cordilleras, and at a very great distance from the sea."—P. 666.

does not form equally on all substances, because different substances radiate heat with various degrees of force, and a scale may be formed of these substances, showing their radiating powers—as, say, Wool, Cotton, Down, Grass, Leaves, Sand, Glass, Porcelain, Varnish, Wood, and Metals.

From this scale it appears that the best radiating bodies are organic and silicious, and this is more particularly the case when they present large surfaces, from which the heat can pass freely. Any thing that tends to compress or condense the substance into a more compact body, injures its radiating power. Thus a loose fleece of wool, if compressed into a comparatively solid mass, will not radiate equally well; whilst polishing a piece of metal will deprive it of a portion of its radiating power.

Why there should be this difference in the radiating powers of substances, we do not know. There seems to be some relation between the conducting and radiating properties of various bodies, the best conductors being the worst radiators. The extent of surface also appears to have considerable effect, as the greater the surface the greater the radiation; hence the large amount of radiation from leaves of trees and grass.

Counter radiation has, however, wherever it takes place, its full degree of effect in producing the general result. The under sides of the upper fibres of loose wool and leaves of trees, like a cloud above the earth, will radiate heat downwards, and to a proportionate extent counteract upward radiation from lower objects. And any contiguous lateral substance will have a similar effect, as it will reciprocate the radiation. A covering of the slightest kind may thus counterbalance the upward radiation.

Radiation of heat is, then, the cause of that cooling of the surface of the earth during the night which takes place under a clear sky, and that produces liquid dew on the

earth: but the cooling thus produced is not equally great in all parts under apparently similar circumstances. It is the greatest in the interior of large continents, and more particularly where there is a very dry atmosphere, as in parts of Russia, the Desert of Bokhara, the great Desert of Northern Africa, and other similar parts. Accounts of travellers in such places represent the cold produced in them by radiation during clear nights, as being more intense than in other countries having a damper atmosphere. The cause of this difference is, however, not to be sought for in any greater clearness of the atmosphere in dry than in damp countries, as the fact is rather the reverse of this, the air being somewhat clearer in the damp countries; but in a process which, when dew is formed, always counteracts to a certain extent the cooling effect of radiation.

When radiation cools the surface of the earth so much as to condense and liquefy some of the aqueous vapour that is in the air, that liquefaction liberates much heat: and this heat tends to warm the part that is in course of being cooled by radiation. There is, then, a double process going on at the same time and in the same place. Radiation is cooling the part, whilst liquefaction of vapour is warming it; and, under these circumstances, it is only to the extent that the influence of the former exceeds the latter, that cooling is accomplished. When there is much vapour in the atmosphere, much of it is soon liquefied, and the cooling effect of radiation is thereby counteracted to a great extent; when there is little vapour, there is less liquefaction of that vapour, and cooling is consequently less counteracted. And where the atmosphere is so dry as not to admit the liquefaction of any vapour from the degree of cold that exists, radiation produces its effect without being in any degree counteracted by recently liberated heat.

In such dry deserts as those referred to, the cold in the early part of the night, when it produces dew, produces a

only on the best radiators, which are generally the few vegetables that are found in the deserts; and, as the cold increases, worse radiators have dew deposited on them successively in the order of their radiating powers.

In our own country, from the operation of the cause here pointed out, radiation does not produce that intense cold in the early part of the winter, when the dew-point is comparatively high, that it does at a later period of the season, when the dew-point is very low. In the latter part of the winter, as there is not sufficient vapour to permit much of it to be liquefied by the cold of radiation, that cold may, and frequently does, go on increasing without counteraction during the absence of the sun.

Thus we find that vapour, when condensed into liquid by cold, always gives out heat; whether it is in the formation of the cumulous cloud in the higher regions of the atmosphere, in producing mist near the surface of the earth, or in the production of dewdrops on the surface, the same effect is experienced; and, wherever heat is liberated, it must have its degree of influence in counteracting the cold of radiation.

It has been stated, that "metals give to glass near which they are placed, the property of more speedily attracting caloric from hot air; and, on the contrary, that of yielding it more speedily to cold air," because a mercurial thermometer accommodates itself to a higher temperature sooner than an air thermometer. But this may be because the heat which passes into the glass tube of the thermometer is rapidly absorbed by the mercury. In like manner, when placed in a colder medium, the heat of the mercury is conducted to the inner surface of the glass tube more rapidly than is the heat of the inclosed air; the mercury therefore cools quicker than the air. But these results are consequences of mercury being a better conductor of heat than air is. And when a piece of foil is placed on the inside of a pane of glass, the outside of the glass opposite the foil is not so soon cooled

by radiation, because the metal furnishes heat to supply the place of that lost by radiation from the glass.

We may then say that "*falling dew*" is produced by the descent of the cumulus or day-cloud, which, cooled by evaporation in a higher part of the atmosphere, sinks in the evening to the surface of the earth. *Floating dew* is found in parts which have much vapour in the air in proportion to the temperature, along with a clear atmosphere, and when, consequently, radiation from the surface cools the atmosphere contiguous to it, and condenses a portion of the vapour which the air contains into minute globules of liquid, which are sustained by the elastic force of the air; whilst *dew*, properly so called—that which is found attached to various substances in the form of drops—is a result of the cooling of certain bodies below the dew-point of the atmosphere by radiation of heat from those bodies, and a consequent condensation and abstraction of some of the vapour which the air resting on them contained. And the more any body is thus cooled, the greater will be the quantity of dew deposited on it. In the two last-mentioned modes, dew supplies to a certain extent the place of rain. Where clouds are freely formed, rain falls on the earth to some extent; but when rain is absent, and the sky is cloudless, radiation of heat, by cooling and condensing vapour, gives some moisture to the earth. Thus the sands of Africa and Asia, which are never visited by rain, have their scanty vegetation supplied with a certain amount of that moisture which is so essential to the life of organized beings.

ESSAY VII.

On the means of computing the quantity of Aqueous Vapour in a Vertical Column of the Atmosphere.

If there were an empty atmospheric space over the surface of our globe, the vapour which would arise from water by the process of evaporation, would, by its elastic force, expand upwards, and constitute an atmosphere of pure vapour, of a height and density that would be determined by the temperature. As explained by Dalton, the density would be the greatest in the lowest part, as the portion in that part would sustain the whole incumbent mass, and would be less in higher parts, until at a great height the density would be inconsiderable, the vapour being greatly rarefied by its own expansive force. The temperature would not be the same at the different heights, but, in accordance with the known laws of cooling by expansion of all aëriform substances, it would diminish as the vapour expanded.

In such an atmosphere the temperature and density at different heights may be presumed to be as expressed in the following table, No. 1, where the temperature and dew-point at the surface is assumed to be 50°; and the quantity of vapour at certain heights would be as great as could exist in the aëriform state at each height.

Table No. 1.			Table No. 2.	
Yards in Height.	Temperature of an Atmosphere of Pure Vapour.	Tension of Pure Vapour Atmosphere.	Temperature of a Gaseous Atmosphere.	Tension of Vapour in a Mixed Atmosphere
4,000	42°	.283	10°	.089
3,500	43°	.293	15°	.108
3,000	44°	.304	20°	.129
2,500	45°	.315	25°	.155
2,000	46°	.326	30°	.186
1,500	47°	.337	35°	.222
1,000	48°	.349	40°	.264
500	49°	.361	45°	.315
0	50°	.373	50°	.373

In these tables we see that while at a height of 1,000 yards the vapour has cooled only 2°, the gases at the same height have cooled 10°; and if these two atmospheres existed separately, they would have the respective temperatures there given throughout their columns. We know, however, that in our atmosphere these aëriform substances are intermixed *and diffused through* each other; and as contiguous substances part with heat, and communicate it to each other until an equality of temperature is attained, the different temperatures of the two atmospheres could not be retained at the various heights. In the higher parts, the warmer vapour would part with heat to the colder gases until equality of temperatures was established in the mixed mass.

In our gaseous atmosphere, receiving, through evaporation a quantity of vapour expressed by a dew-point of 50°, at the surface of the earth, the proportions of the masses of vapour and of gases, according to the present mode of determining them, is said to be, say as 1 to 79, that is, one of the former to seventy-nine of the latter; but as the vapour in this mixed atmosphere originally ascended, and diffused itself through the gases, it must have been by them cooled in its passage below the temperature it would otherwise have retained. The

whole atmosphere would therefore be cooled, not according to the separate laws of cooling by expansion of the different aëriform substances of which it was composed, but according to the laws of cooling of that part which constituted 79 parts out of 80 of the whole mass. The vapour, therefore, would be cooled by the law of cooling of the gases with which it was intermingled, and the table No. 2 would express the final diminution of temperature of the mixed atmosphere whilst its constituents remained in the aëriform state.

It has been shown, that in an atmosphere of pure vapour of 50° of temperature at the surface, of 51° at 500 yards of height, and of 1° less for every additional height of 500 yards, each elevation might have the maximum quantity of vapour that could exist in it at that height. And if any part of the atmospheric space should be then cooled down below the temperature of the height, a portion of the vapour would be condensed into water. It follows, therefore, that when vapour escapes from water, by evaporation, into a dry gaseous atmosphere of the temperature of 50° at the surface, that vapour, in expanding into the space above, will be liable to be condensed by the cold of the gases. When the vapour expanded to the height of 500 yards, the quantity that could exist in the aëriform state would be not that of .361, which belongs to a temperature of 49° of pure vapour, but only that of .315, being the maximum quantity for the temperature of the gases at that elevation; and the difference between the quantities of vapour expressed by .361 and .315 would be condensed into water. Inferring the quantity of vapour that exists in the atmosphere from the dew-point at the surface, according to the law of cooling of the vapour, would therefore involve an error of excess in the amount of vapour equal to that contained between .361 and .315, the maxima quantities of the respective temperatures of 49° and 45°.

In like manner, with the same dew-point at the surface, and

the quantity of vapour belonging to it in a mixed atmosphere, there would be, at the height of 1,000 yards, a dew-point of only 40°, and the conclusion arrived at from the dew-point at the surface would be erroneous to the extent of the difference between .264 and .349, the vapour belonging respectively to the dew-points of 40° and 48°; the latter being the quantity that would be found in an atmosphere of pure vapour, and the former the maximum quantity that can exist in the temperature of the upper portions of vapour, as that temperature is determined by the gaseous atmosphere. The same kind of statement will equally apply to all other elevations, the conclusions generally drawn at present involving an error of excess in the quantity of vapour existing in the atmosphere. The parallel columns in the table showing the respective temperatures of a gaseous and of a vapour atmosphere at various heights, both being of the temperature of 50° at the surface, show the difference in the quantity of vapour that can exist in each of them at the heights named; and this difference expresses the amount of error involved in the present mode of deducing the quantity of aqueous vapour in the atmosphere from the dew-point.

In order to ascertain the real quantity of vapour that can exist in our atmosphere, we must take the amount which belongs to each dew-point in one of pure vapour, from the surface upwards, and the quantity belonging to each lower degree of temperature that is found in the gaseous atmosphere at the same heights; and supposing that every height had its maximum quantity of vapour, the difference between the two subtracted from that which would exist in a vapour atmosphere will give the real existing quantity.

This would furnish the limit of the quantity that is determined by the respective laws of cooling by expansion of the aëriform substances of which our atmosphere is composed. But the alterations that take place in it are more complicated than those which arise from cooling alone. As vapour rises

in the atmospheric space, and is cooled by the gases, condensation takes place, as already stated, when a new process commences. The condensing vapour gives out heat, and raises the temperature of the gases, and this rise permits more vapour to exist in that part than could have remained before the condensation and consequent heating occurred: the liberated heat, at the same time, carries the whole mass of the atmosphere to a greater height. In this way condensation of vapour causes it to ascend to superior elevations, and produces local zones of vapour at particular heights, denser than what belong to those heights in an undisturbed atmosphere.

The disturbances by condensation are, however, so irregular, as to render it difficult to arrive at a mean result of any number of cases. The greater the amount of condensation in a given time, the greater will be the rise of temperature in the locality; and, consequently, the more vapour may exist there in an uncondensed state, and be borne to a higher region to be successively further expanded, cooled, and condensed. In this way, in a thunder storm, there may be a large quantity of vapour in a particular mass or column of the atmosphere borne to a great height, to be there condensed by the cold consequent on the diminution of incumbent pressure. It thus appears that the separate amounts of the gases and of vapour in an atmospheric column which constitute the whole atmospheric pressure, as measured by the barometer, cannot be easily ascertained, particularly when the atmosphere is much disturbed by the condensation of vapour.

But it may be asked, what causes the vapour in the mixed atmosphere which has less incumbent vapour pressure, to show so high a dew-point at the surface? To this question the following answer may be given:—

When vapour rises from water, it has a certain amount of elastic force which is exerted in an effort to expand upwards into the atmospheric space; but it there encounters an impediment in the gases which exist in that space, and through

which it has to penetrate. The surface of the water constituting a base on which the vapour rests, its elastic force is exerted to penetrate or remove the gases that it encounters; and in proportion to the resistance of those gases is the elastic force or tension of the vapour accumulated, until it becomes sufficient to penetrate them and diffuse itself in an aëriform state to the extent that temperature will permit. In our mixed atmosphere, therefore, the dew-point that is found at the surface is attributable, partly to the pressure of the vapour contained in the incumbent column, and partly to the resistance of the gases to the rising of fresh vapour. As the rising vapour forces its way through the impeding column it becomes at some height condensed by the cold that exists there, when fresh vapour springs from the surface to go through the same course.

It has however been said, that heating and cooling being opposite processes, it is impossible to have them going on together in the same column of the atmosphere. But this assertion evidently has been made from a misconception of the case, consequent on not attending to the order in which the various operations are carried on. It is admitted by all parties, that when gases are taken to a higher part of the atmosphere, they cool by the expansion which is consequent on the removal of some of the incumbent pressure to which they are subjected,—and as vapour is intermixed with, and diffused through them, a part of the vapour may be condensed by the cooling of the gases. On this taking place, the latent heat which had been dormant in the vapour is set free, and it raises the temperature of the part, and, consequently, of the gases that are in the part;—this is the first step in the process. But it is clear that this increase of the temperature of the gases will cause them to expand, and enable the adjoining gases which have not been warmed, and are therefore heavier, to force up those that have;—the warmed gases will thus be made to ascend to a higher part of the atmosphere. The

expansion and ascension of the gases are, in fact, direct consequences of the heating caused by the condensation of vapour.

When the gases are thus forced to a greater height in the atmospheric space, they become subjected to a reduced amount of incumbent pressure, and they expand and cool to a greater extent as a consequence of that alteration. This second cooling condenses an additional quantity of the vapour that is in the ascending column, and the additional condensation sets free a fresh portion of heat. It is a second process of the same nature as the first;—the renewed cooling after the first heating having been produced by the further reduction of incumbent gaseous pressure, and then the additional condensation is effected, by that renewed cooling. The cooling and heating processes of expansion and of condensation are separate and successive—the one being consequent on the other,—and, proceeding by alternate operations, each in its turn produces the other. And, although the separate operations take place in such rapid succession as to prevent our distinguishing where the one operation ends and the other begins, we know from their nature that they must be separate and successive, the gases being regularly cooled by expansion until they condense vapour, and then the vapour heating the gases and expanding them. It is the mechanical intermixture of the two aëriform substances that enables them to act and re-act on each other, the chemical power of cooling by expansion of the one, being able to draw forth the latent heat of the other, by condensing it while they are intimately diffused through each other by their mechanical intermixture.

ESSAY VIII.

On Alterations of the Atmosphere at Makerstoun.

In meteorological investigations much difficulty is expe-enced in tracing the causes of changes in the atmosphere, ı consequence of the extremely elastic and moveable nature f the materials of which it is constituted, and the height in ıe aërial ocean at which the changes generally occur. Any isturbance, originating in a particular locality, acts readily n adjoining parts, giving rise to other disturbances that are ften nearer to the observer, but which together produce such iversified movements and appearances as to create much com-ılexity. And this renders it very difficult to say what was he earliest, or prime moving force, or to distinguish from t the early effects which subsequently became continuators ınd propagators of the disturbance. If we fix upon any ɔne time to make observations, these difficulties become so great as to make it almost impossible to trace out the first or primary disturbing force. It is only when the cause acts continuously during a certain period of time, and produces uniform effects at recurring periods, that we are able to trace and follow the connection that exists in such way as will warrant us to place reliance on the conclusions to which the facts seem to conduct us.

Changes of season in different latitudes, although constantly producing effects of a certain kind on the temperature and movements of the air, are frequently very irregular in their times of occurrence, and the investigator finds it difficult to

ascertain the particular cause that is in action in any locality at any one period to create the irregularity. It appears sufficiently certain that the unequal heat of the sun in different seasons and latitudes, is the great general disturbing cause, but the way in which it operates in each case to produce such various results is not equally clear. We therefore are obliged to direct our attention more particularly to those alterations which take place with the greatest degree of regularity, in order that we may, by observing the various phenomena preceding, accompanying, or following them, ascertain the kind and amount of disturbance that is produced in each separate alteration, and the precise time of its occurrence.

The semi-diurnal alterations of atmospheric pressure, as indicated by the barometer, take place at such times and with such regularity as appear to connect them with the movements of the sun,—they have therefore been generally attributed to the direct influence of that luminary on the temperature of the atmosphere. And, as has been before stated, attempts have been made to shew that the successive changes of atmospheric temperature, which arise directly from the daily movements of the sun, are the cause of the semi-diurnal fluctuations of the barometer, and of the alternating winds called sea and land breezes.

In a former essay on meteorological observations made at Bombay, I endeavoured to explain the way in which the hourly atmospheric disturbances that take place in that part of the world are really produced, and attempted to shew that they are effected not by direct solar influence, but indirectly, through evaporation of water and condensation of vapour altering local atmospheric temperature in the higher regions.

Hourly observations have been made in other parts of the world which exhibit the same general features and character as those made at Bombay, and they all, as far as my information extends, point to the same general conclusions. Such observations are registered in many places, and among others

at Makerstoun;—and as this place is in a high latitude, 55° 34′ 45″, it seems desirable that the facts observed there should be investigated, and their causes traced as far as is possible.

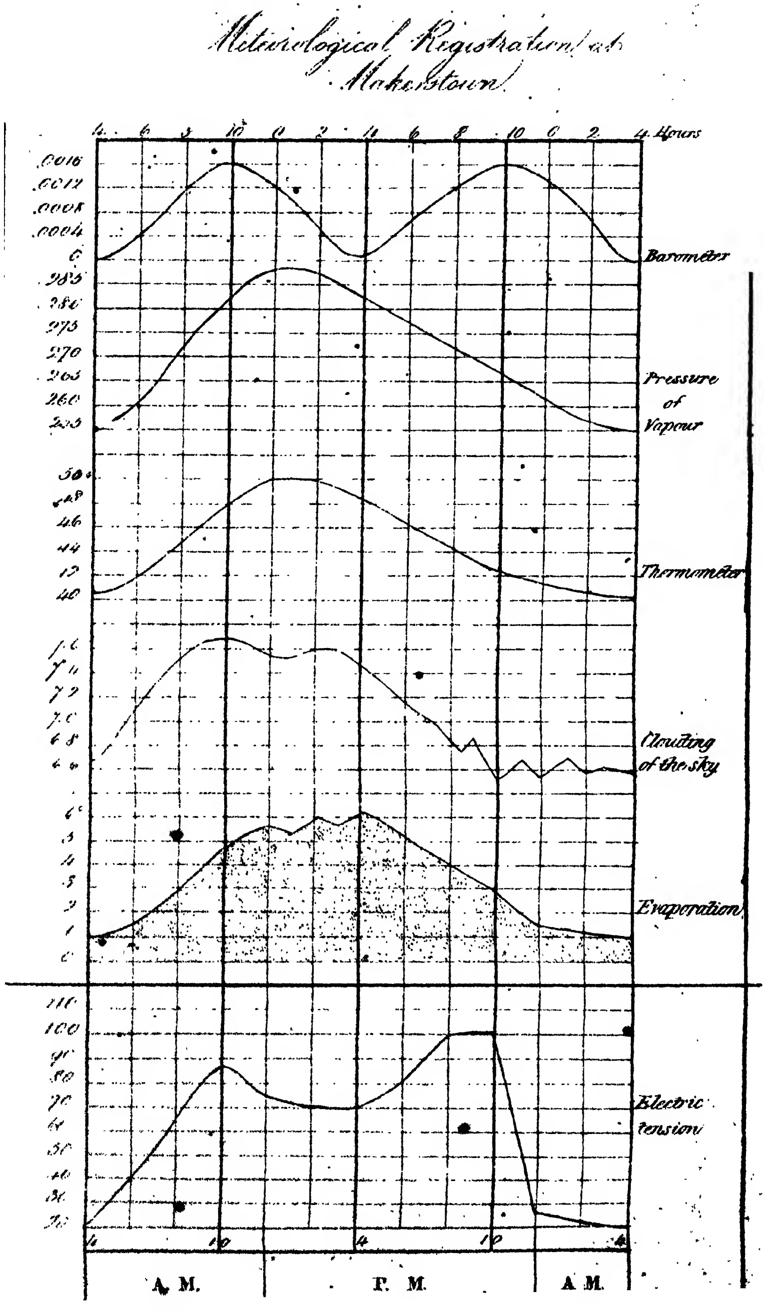
The accounts which I have seen, and which it is proposed to examine, are for the year 1844; and in them we have hourly registrations of the heights of the barometer,—the temperature of the air,—vapour pressure,—*and the clouding of the sky*, with the yearly average of each hour. As in the returns from Bombay, these indicate that the real primary cause of the semi-diurnal fluctuations of the barometer is not that which has been hitherto generally supposed, but such as I have pointed out.

In the accompanying diagram,* I have represented the daily commencement of the hourly registrations at four o'clock in the morning. By reference to this diagram, it will be seen that in Makerstoun, as in many other places, the barometer rises from 4 to 10 A.M., and again from 4 to 10 P.M. And it falls from 10 A.M. to 4 P.M., and again from 10 P.M. to 4 A.M., making two risings of six hours each and two fallings in equal times. The thermometer, as in other places, has one rise and one fall only;—and in this respect vapour pressure, when separated in the ordinary way from gaseous pressure, resembles temperature having only one rise and one fall in the twenty-four hours.

By observing these facts, it will be seen that during the first six hours of the meteorological day the barometer rises .0016 of an inch of mercury, indicating that the total atmospheric pressure had been increased to that extent. And during the same six hours temperature increases from a little less than 41° to more than 47°, being above 6°. Now the tendency of this increase of temperature is evidently to make the atmosphere lighter in the part, and as far as it produced any effect, it must have been to produce a fall and not a rise

* See Plate No. 4.

PLATE 4.



Meteorological Registration at Makerstoun
4 6 8 10 0 2 4 6 8 10 0 2 4 Hours
.0016
.0012
.0008
.0004
0
Barometer
.285
.280
.275
.270
.265
.260
.255
Pressure of Vapour
50
48
46
44
42
40
Thermometer
Clouding of the sky
Evaporation
110
100
90
80
70
60
50
40
30
20
Electric tension
4
10
4
10
4
A. M.
P. M.
A. M.

of the barometer. But it will be seen, that vapour pressure or tension was augmented at the same time from about .253 of an inch of mercury to above .282 of an inch. And as this additional vapour pressure was added to the previous aggregate atmospheric pressure, it must have tended to increase that pressure, and may be assumed to have been the real cause of the rise of the barometer during these six hours.

The next six hours constitute the most interesting period within the range of our inquiry; and during this time we see that the barometer fell from .0016 to .0001, or nearly equal to the whole of its previous rise,—but the temperature and vapour pressure do not change with the barometer and move in opposite directions; on the contrary, their alterations continue in the same direction as before during one-half of the time, namely, from ten to one o'clock. These changes consequently cannot account for the barometer falling, and we are left to trace the cause which came into operation at ten o'clock to produce that effect.

While the barometer was falling after ten o'clock, the temperature of the air rose from a little more than 47° at 10 A.M. until at 1 P.M. it reached about 51°, being a rise of about 4°, whilst the vapour pressure further increased from .282 to .290. These two causes must, therefore, during these three hours, have acted on the barometer in the same direction, and with nearly the same force that they did during the first six hours. If then these two causes alone had been in action, the barometer must have continued to rise from ten to one o'clock; but we see that it fell in that time from .0016 to .0008. From these facts and the times of their occurrence, it follows that neither the joint nor the separate influences of thermometric temperature and vapour pressure can account for this fall of the barometer.

In the next three hours, namely, from one to four, the curve of temperature and that of vapour pressure move nearly together, but both declining a little,—the fall of the temperature

having a tendency to make the air heavier, and the decline of vapour pressure tending to make the atmosphere lighter; both, however, tending to produce results the opposite of those which had been experienced in the previous three hours. But we see that the cause of the fall of the barometer at ten o'clock, whatever that cause may be, continued to act steadily in the *same direction* in the whole of the six hours from ten to four o'clock. During this time, therefore, it may be considered that the registrations of the movements of the barometer,—of the temperature, and of the vapour pressure,—do not enable us to account for the fall of the barometer, and we have to trace the cause which apparently came into action about ten o'clock in the morning, and produced the new effect. This I have formerly endeavoured to shew is the condensation, at that time, of some of the vapour that rose in the course of the morning, which condensation warmed a part of the atmospheric column, increased the expansive force of the gases, removed a portion of the weight of those gases in the part, and thus made the barometer fall. This cause continued in operation while the sun retained power to raise sufficient vapour from the surface of the earth to carry on condensation in the upper part of the atmosphere, which is shown to be until about four o'clock in the afternoon.

It will, I presume, now be admitted that the cause here pointed out, supposing it to come into operation in the way described, is adequate to the production of the effect ascribed to it, as the condensation of aqueous vapour is known to be able to warm the air, and temporarily reduce its weight and pressure in the locality. But it has been asserted that we have not sufficient evidence that vapour is condensed in the locality when the daily fall of the barometer occurs, and therefore that that condensation cannot be safely admitted to be the cause. We have, however, numerous accounts of the daily condensation of vapour, and of the consequent formation of cloud about the hour required, in many parts of the

world, and particularly in those where the daily fall of the barometer is the greatest, such as in Jamaica and on the west coast of tropical America. It must be acknowledged, however, that observers in those parts have not attempted to trace a connection between the facts.

But in the Makerstoun observations we have hourly accounts of the extent of cloud that covered the sky, and these are represented in a separate diagram. The manner of observing and registering the clouds is thus described. The writer says—"The extent of sky clouded is estimated, the whole sky covered with clouds being rated as ten, and the complete absence as zero." (Page lxii.) From the diagram of this registration it will be seen that after 4 A.M., the commencement of the meteorological day, cloud began to cover the sky rather more fully. This was when evaporation became more active, and a little before vapour pressure began to increase: and the rise of temperature, the increase of vapour pressure, and the additional space of sky covered with cloud went on increasing until eight o'clock. After this time, I have observed that cumuli generally form, which have a greater height or depth rather than a larger extent of surface at the base. But still, from eight in the morning till four in the afternoon, the sky at Makerstoun, as appears from the registrations, was more fully covered with cloud than at any other time of the day. These Makerstoun returns, therefore, by shewing an increase of cloud up to eight in the morning, the cloud continuing until four in the afternoon, if they do not prove the fact, countenance the hypothesis that condensation of vapour, in the formation of cloud, warms the atmosphere, and renders it lighter during this period.

It should be borne in mind that the fall of the mercury after ten o'clock in the morning, whilst vapour continues to pass freely into the atmosphere, to increase its total weight and pressure, constitutes the great difficulty in attempting to account for the semi-diurnal fluctuations of the barometer.

But when it is shown that that vapour is conveying into the atmosphere the heat which it holds in a latent state, to be rendered active and sensible by condensation while cloud is forming, the difficulty is removed. That vapour must be passing into the atmosphere at the required time, is to be inferred from the increase of temperature up to one o'clock, as well as from what has been before stated; but there is other evidence to prove that vapour, to continue the condensation, was supplied up to four o'clock, the time during which the barometer continued to fall.

This evidence is furnished by the registrations of the wet as well as the dry bulb thermometer. The wet bulb, be it remembered, is kept at a lower temperature than the dry one through the cold produced by evaporation of water, with which the former is covered. And the extent of the reduction of temperature by this cause marks the energy of evaporation, and of course the different quantities of vapour sent into the atmosphere in each hour of the day. There are no tables nor any diagram in the Makerstoun returns, to show this directly, but I have ascertained the mean difference between the heights of the wet and dry bulb thermometers for every hour of the day during the month of July; and as that month may be taken as exhibiting the results of evaporation, at the time when it is the most active and energetic, it serves our purpose better than the mean of each separate hour for the whole year. These hourly differences are shown in a diagram in the lower part of the plate No. 4, constructed on the same principle as that in plate No. 3.

The base line represents a state of the atmosphere when the two thermometers would show the same temperature, which would be when there was no evaporation from the water; this state is seldom found, but it furnishes the line from which to measure the amount of difference between the two instruments at different times. A vertical scale of degrees is then formed, marked by lines and figures on which the differences

are marked at each hour. In this way we are enabled to see at a glance that at four o'clock in the morning, in the whole of the month of July, the mean difference between the wet and the dry thermometers is only a little more than 1°. From this hour, through an increase in the energy of evaporation, the mean difference increases until at ten o'clock in the morning it reaches about 4¼ degrees. Now we may safely infer that this more energetic evaporation must by this time have thrown a considerable quantity of vapour into the air, and that circumstance accounts for the greater extent of cloud that was observed, as well as for the increase of vapour pressure. But as we proceed, this diagram shows also that from ten o'clock in the morning to four in the afternoon, the energy of evaporation was still greater than in any portion of the previous six hours, and it increased irregularly up to four o'clock, at which time it is found to be the greatest. It is true that during this latter six hours there was no increase in the extent of sky covered by cloud, though vapour must have been constantly passing into and accumulating in the atmosphere in some state of existence. But the obvious inference from this is, that the additional quantity of vapour was condensed in the formation of hills of cloud (cumuli), in which process it must have warmed a thick stratum of the atmospheric gases, and thus caused the barometer to fall.

At 4 o'clock P.M. we see that evaporation from the surface of the wet bulb must have reached its highest point, the difference between the two thermometers being then about 6°. After this time the evaporation below was less active, the condensation in the upper air ceases, the warming process stops, and the dissolution of the cloud in the higher regions begins to cool the air. For by the same process of evaporation, which now takes place in the higher regions, the conversion of the globules of water that formed the cloud into transparent vapour must take up considerable heat, and that heat will be abstracted from the gases. The atmosphere

would therefore become not only colder, but also denser and heavier,—it would sink into less space and allow additional portions of the adjoining gases to flow upon it, and the barometer would rise, as has been already more fully explained.

Thus we find that the condensation of vapour which evidently took place at Makerstoun from ten in the morning to four in the afternoon, as at other places, warmed the air and made it lighter, whilst the evaporation of cloud which occurred from four to ten in the afternoon, cooled it and made it heavier. The one process had an effect on the gases of the atmosphere the reverse of the other, and produced opposite results on the barometer;—and an examination of the registrations made in that place of the alterations of the barometer,—the thermometer,—the vapour pressure,—the extent of clouding of the sky, and the energy of evaporation—all point at the processes of condensation of vapour, and evaporation of cloud, as being the causes of barometric fluctuation in the two six-hourly periods.

ESSAY IX.

The Phenomenon of Mirage.

That peculiar appearance called "Mirage," has often arrested the attention of travellers and others, and it has been generally considered an effect of refraction of the rays of light while passing through air of various densities. It is described by Kaemtz, in his work on Meteorology, p. 421. In accounting for it, this writer says—"The mirage, for the most part, occurs in extensive plains, when the weather is calm and the ground heated by the sun. The plains of Asia and Africa have become celebrated in this respect: thus, during the Expedition in Egypt, the French army frequently experienced cruel deceptions. The ground of Egypt forms a plain perfectly horizontal; the villages are situated on small eminences. In the morning and evening they appear in their proper places, and at their real distances; but when the ground is highly heated, the country resembles a lake, and the villages appear to be built on islands, and reflected in the water. As we approach, the lake disappears, and the traveller, devoured by thirst, is deceived in his hope." "Although it is more common in the East, yet the mirage exists in our plains much more frequently than is imagined, especially when we bring the head near the ground. I have observed it in the neighbourhood of Hallé, in the country of Magdeburg, and on the coasts of the Baltic, where I often have thought myself in the midst of a large bed of water."

Further on the same writer says—"There is a mirage, in the proper acceptation of the term, when we see below the

object its inverted image, and then the air is hotter in the neighbourhood of the ground than at a certain height. This phenomenon evidences an abnormal state of the atmosphere, and the calm indispensable for its production is often troubled by ascending currents and violent gales of wind, so that several observers say that the mirage is the precursor of a tempest."* This explanation is sufficiently obscure, but it is a fair sample of accounts of mirage that are to be found in books which treat on the subject. These accounts, however, almost universally attribute the phenomena to *refraction of the rays* of light while passing through strata of air of different densities.

Having observed an appearance at Southport, on the Lancashire coast, similar to what the mirage is represented to be, but which did not seem likely to have been produced by refraction, I resolved to revisit that place, in order to take more particular notice of the phenomenon, and the following is the substance of notes made at the time:—

"May 29, 1849.—At from 10 to 11 o'clock, A.M., walked on the sandy shore from the north end of the pier. On moving across the sands towards the sea, the tide being out, looking towards the north, I saw a bluish streak or line a little above the level of the sand, which I recognized as a slight display of the mirage that I had noticed at a former period. It had the appearance of a blue mist, and as I descended deeper into the sand troughs which the retiring tide had left in the shore, the mirage seemed to rise more fully into view. It now presented the appearance of a blue band with a level surface, like that which is seen when looking at distant water; and it reflected objects just as water does. From one point of view, a house was seen above and beyond the blue band, and the image of the house was reflected from the surface of the mist as distinctly as if it had been reflected from the surface of clear still water. On walking further

* Kaemtz, p. 422.

down towards the sea, and then turning towards the mirage, I found that when within one of the deep troughs made by the retiring tide, the view of the mist was intercepted by an intervening sand-bank. The house and dry sand hills near it were still seen, but the mirage was hidden by the intervening ridge of sand. Moving towards the place where the mirage had appeared, on ascending the ridge it gradually came again into view, and had every appearance of water, reflecting the objects which were beyond it and above the level of the surface.

"I was now about a mile from the house and the dry sand hills, and as I proceeded towards them, I noticed that the level sand had been covered by the water of the last tide, which was at about five o'clock in the morning, and the sand was yet quite moist. As I advanced the mirage became less, until, when within about three hundred yards of the part where it had appeared, it vanished. The surface of the shore here was of darkish moist sand, but covered with tufts of grass sufficient to make it rather green; there was nothing, however, to indicate what had caused the appearance of mirage.

"Having brought a thermometer with me, I swung it in the air, while exposed to the sun, at the height of about eighteen inches from the ground, in order to bring it to the temperature of the air. It settled at 71° Fahrenheit. I now placed the instrument on the ripple of the moist sand, and in thirteen minutes it indicated a temperature of 91°, having in that time risen 20°. The sky was partially and irregularly covered with light fleecy clouds, allowing the sun to shine through them. Again I held the thermometer in the air, with the bulb exposed to the sun for thirteen minutes, when it marked a temperature of 73°, having sunk 18° in the air. These experiments I repeated, and found them substantially the same.

"I now walked to the dry shore, and placed the thermometer on a sand hill, when it rose to 98°, and on waving it

in the air, whilst returning to the moist shore, it sank to 68°; thus showing a difference of 30° between the temperature of the dry sand and of the air. I afterwards repeatedly exposed the instrument to the air, and placed it on the moist sand, in both cases exposed to the sun, and found the difference in the temperature of the two to range from 15° to 20°."

These facts appeared to show that the sun heated the shore until it became considerably warmer than the air that rested upon it; and where the shore was moist, this heating would vapourise some of the water that was in it, and aqueous vapour would be formed and passed into the atmosphere. That this process was going on at the time seemed evident from the prominent parts of the sand ripples becoming sensibly drier than the parts less prominent. The moist sand being heated up to (say) 90°, evaporation belonging to that temperature would take place from the surface; but the vapour thus produced would spring into air of a temperature lower by (say) nearly 20°. It would follow that a part of the vapour which had been produced by a temperature of 90°, would be condensed by the cold of 70°, and a mist, or stratum of cloud, would be formed in the air, at a short distance from the surface of the ground. This stratum being thin, would not be perceptible to a person standing in it, or near to it, though it might be to another person placed at a suitable distance and looking along its upper surface. The mass of air however that was higher, being dry, the small globules of water that constituted the mist near the ground would evaporate almost immediately after they had been formed, leaving the air transparent above the upper surface of the mist; and an observer, at a sufficient distance to be able to see a certain extent of the surface, would find it reflect light in a similar way to that in which it is reflected from the surface of water.

On subsequent days I observed the same phenomena, and ascertained that the top of the mist from which the light was reflected, could not be more than eighteen inches from the

ground, and the upper part, at times, had a waving motion, like the top of flame. I traversed the part repeatedly, and saw the same place successively present the appearance of a greenish sandy shore, and a sheet of blue water.

While thus employed, I noticed that a similar mist to that which I knew was forming in the part where I stood, was rising from the river Ribble. It had the appearance of a bluish smoke, terminating in a waving motion, that distorted the objects seen beyond it on nearly the same level. As the day advanced, by selecting a proper station, I could see objects beyond the river reflected from this mist, and distorted by the waving motion; whilst, by stooping down, I could see the waving top of the mist over the sandy shore just above an intervening ridge of sand; or by standing up, see the apparently blue water reflecting the objects beyond it. The mirage was palpable over the river, as well as over the moist sand nearer to the observer.

After many days of observation, I came to the following general conclusions. Until the sun heated the moist ground in the morning above the temperature of the air, no mirage appeared; but when the ground was sufficiently heated mirage began to show itself—at first, faintly; but it increased in strength and fulness as the temperature of the ground rose above that of the air; and it was the strongest, of the greatest breadth, and extended the farthest on the shore, when the sun was most powerful, and when there was the greatest difference between the temperature of the ground and that of the air. At one time the temperature of the dry sand hills was 90°; that of the moist sand, over which the mirage appeared, 75°; and of the air over this moist sand, 60°. The lower temperature of the moist than of the dry sand was a consequence of much of the heat that fell on the former being absorbed by water in its conversion into vapour; and this vapour passed into air sufficiently cold to condense it, and to form a stratum of mist that reflected light when seen from a proper angle.

That objects were reflected from the upper surface of this mist may be safely inferred, because there was nothing else present on the sand to produce the reflection. The appearances could not be results of refraction of light in passing through strata of air of different temperatures and densities, as no such differences were observable in the air; and the stratum of mist, from which the light was reflected, was not more than eighteen inches from the ground. That an abundance of vapour was in course of being produced from the moist sand, was evident from the drying of that sand; and that a part of the vapour would be condensed by the cold air, and form mist at a small height, is equally clear from the known effect of cold on vapour. The height of the surface of the mist from which the reflection occurred would be determined, at each hour, by the energy of evaporation from the ground, the coldness of the air that condensed the vapour, and the degree of dryness above that permitted the mist to evaporate.

The principal conditions required to produce mirage seem to be—a level surface of moist ground sufficiently heated to produce energetic evaporation of water, and a cool and dry atmosphere for the vapour to pass into. If the air is calm the mist appears like still water; but when wind blows the mist is driven by it like smoke, and in this form it may be often seen driven over the sands.

ESSAY X.

Local Irregularities in the Daily Production and Ascent of Atmospheric Vapour.

When making observations at Southport, in the summer, in order to discover the cause of *mirage*, my attention was arrested by the unequal amounts of evaporation from the wet bulb thermometer held in the air which were evidently taking place at the same period of the day, when the sky was in different states. On one day, when thick clouds overspread the sky, and it appeared that rain would soon fall, evaporation was so active from the wet bulb thermometer at about twelve inches above the ground, as to make the difference between that instrument and the dry thermometer as much as 11°.5, whilst on another day, shortly afterwards, at the same hour, when the sky was clear and the sun was shining, the two bulbs showed nearly the same temperature, indicating that no considerable evaporation was then taking place from the wet bulb. The difference thus exhibited in the energy of evaporation on the two days was great, as may be seen more in detail from the tabulated observations that were made on the dry and wet thermometers, on the shore at Southport, on the mornings of the 7th and 9th of July.

Tabular Registration of Meteorological Observations at Southport.

ON JULY 7.				ON JULY 9.			
Time.	Thermometers.		Difference.	Time.	Thermometers.		Difference.
	Dry bulb.	Wet bulb.			Dry bulb.	Wet bulb.	
h. m.	°	°	°	h. m.	°	°	°
10 45	73	62	11	10 47	61.5	60.5	1
10 50	73	63	10	10 49	61	59.6	1.4
10 55	73	63	10	10 51	61	60	1
11 0	72	62	10	10 54	62.4	61.5	.9
11 5	71	62	9	10 56	62.5	62	.5
11 10	72	62	10	10 58	62.4	61	1.4
11 15	71	61	10	11 0	62.5	61.5	1
11 20	71	61	10	11 5	61	59	2
11 25	71	63	8	11 30	61.5	60	1.5
11 30	71	64	7	11 32	61	59	2
11 35	71	63.5	7.5	11 34	60	58.5	1.5
11 40	72	63.5	8.5	11 43	63	61	2
11 45	72.5	62	10.5	11 45	63	61.5	1.5
11 50	73	61.5	11.5	11 47	62.5	60.5	2
				11 49	63	62	1
Mean	71.9	62.4	9.5	Mean	61.9	60.5	1.4

Here we see that the mean difference of temperature between the dry and the wet thermometers on the 7th, was 9°.5, whilst the difference on the 9th was only 1°.4. And these differences may be taken as examples of what frequently occurs in *such localities. Now, when the wet bulb thermometer was so much below the dry one on the 7th, the sky was covered with thick black clouds, which shortly afterwards poured down rain; whilst, on the 9th, when the dry and wet thermometers differed only 1°.4, the weather was fine and the sun was shining with full force from a clear sky.*

These apparent anomalies arise from certain operations that have not been much noticed by meteorologists, but which are often taking place in our atmosphere. When the observations were made on the 7th July dense clouds were evidently forming in an upper region of the atmosphere—that is, the aqueous vapour was there in process of being rapidly converted into

minute globules of water, which remained in the air in the form of dense cloud. This process not only relieved the transparent elastic vapour that was nearer to the earth from part of the incumbent vapour pressure, and allowed the vapour which was below to expand upwards more freely, but also, by warming the locality where the condensation took place, produced an ascending current of air, which, carrying up the vapour that was in it, allowed that which was produced from the surface to expand more freely into the higher regions. Hence, the rapidity of evaporation from the wet bulb thermometer suspended near the surface on the 7th, and the consequent great difference of temperature between it and the dry one, amounting to no less than 9°.5.

On the 9th circumstances had altered—as the clouds had entirely disappeared. The unobstructed rays of the sun heated the ground to a high temperature, producing abundant evaporation. But the vapour thus produced passed into the air under the full pressure of the incumbent mass that already existed in the atmosphere. The newly evaporated vapour, therefore, did not rise freely, nor expand rapidly into the higher regions, as it had done on the 7th, but was kept down to a certain extent by air at rest and incumbent vapour pressure, and the vapour formed a stratum near the surface of the earth, of a certain thickness and density; and any wet substance, such as the wet bulb of a thermometer, placed in this stratum would evaporate water but feebly, and would be cooled by evaporation but in a small degree. Under these latter circumstances, the more powerful the sun's action on the moist ground, the more fully would the air near the ground be charged with vapour, and the more completely would evaporation be checked from any wet body suspended in the air. On the 7th, the temperature of the moist ground was, say 74°, and of the air, nearly 72°, making a difference of only 2°; whereas, on the 9th, the ground was 76°, and the air not quite 62°, making the difference between the ground and the

air as great as 14°. And this great difference in the temperature of the ground and of the air in the latter case was, doubtless, the cause of so much vapour being found near the ground, its expansion and diffusion in the higher regions being checked by incumbent pressure and still air. The large quantity of vapour produced from the ground would, however, exert its elastic force and expand upwards; and at some height it would encounter air cold enough to condense a portion of it, when incipient cloud would be formed. But the sun shining on the upper surface of this cloud, might have sufficient power to re-convert it into transparent vapour; and in this way, vapour may successively pass into higher regions cold enough to condense it, and be re-evaporated by the direct rays of the sun that shine upon it.

When watching the thermometers on the shore at Southport, whilst the sun was shining strongly upon them, I was occasionally surprised to find the mercury sink one or two degrees, in a short time, without any apparent cause. But more attentive observation showed that, at the time when the mercury thus sank, there was a darkening of the sky, the sun's light being evidently diminished by something in the air which was not palpable cloud. From repeated observations of such phenomena, and from a review of all the circumstances attending them, it appeared probable that portions of the vapour which had been recently produced at the surface of the earth were expanding into the higher regions of the air, and were meeting with strata of air cold enough to condense them and to form incipient cloud; but which cloud was shortly afterwards dissolved by the direct rays of the sun that was then shining. The diminution of the brilliancy of the solar light, and the accompanying cooling of the thermometers, seldom lasted long; but the occurrence was not unfrequent in the hotter part of the day on the 9th of July, and it was observable at many other times when the circumstances were similar in their character.

If there were no wind to carry the saturated air horizontally to a distant part, the vapour produced by evaporation in the way described would always, in due time, expand upwards until it met with a degree of cold in the higher regions, sufficient to condense it more rapidly than the sun acting on the upper surface of the mist could dissolve it—when palpable cloud would form; and this seems to be the way in which daily cumuli are formed in many parts of the world. In these parts, at some certain heights determined by the expansive force of the vapour and the cold of the gases into which it passes, these cumuli are formed every morning, as soon as the sun has evaporated sufficient vapour from the surface of the land or sea. And when the cloud is formed, incumbent vapour pressure on the lower vapour is diminished, and evaporation goes on more freely, not only from the surface of the ground, but also from a wet bulb thermometer placed immediately above that surface, although the temperature at the time may not be very high; and this accounts for the energy of evaporation that took place on the cloudy 7th July, from the wet bulb of the thermometer. On that day, the vapour that had been produced from the surface of the ground not being kept down by strong incumbent vapour pressure, passed rapidly into the upper regions of the atmosphere, when an ascending current, produced by cloud formation, carried it to a higher and colder region, where it became rain, to descend to the earth from which it had previously risen. Since that time, I have frequently observed similar phenomena in other parts.

Evaporation of water and condensation of vapour, alternating at various heights in the atmosphere, sometimes produce singular appearances. On one day, at about two o'clock, when on the sands whilst the tide was down and the sun was shining with great power, on looking towards Southport, I observed a strange appearance in the air, in the front of the village. The people on the sands at the time were numerous, some

walking, others riding on donkeys and in carriages; but all appeared to be in the air, inverted, and at the same time much distorted, frequently changing their forms like a dancing phantasmagoria. I had no meteorological instruments with me at the time, but, from the state of the weather, the appearances might be accounted for in the following manner:—The sun was vaporising water freely from the heated moist sand of the shore, and the vapour thus produced, as it ascended in the air, was partially condensed, and formed local strata of incipient cloud, which were dense enough to reflect objects that were on the shore. But these strata of cloud were soon afterwards evaporated by the rays of the sun, and the condensation and subsequent evaporation produced such unequal densities in the air as to cause great refraction of the light, in addition to the reflection from the surface of the incipient cloud. Thus the spectator experienced the effects of reflection and of refraction combined and acting on an irregular ascending stream of vapour springing from the moist sand. It was only when at a certain considerable distance from the appearances that they could be seen—on approaching the spot the whole vanished, and the persons on the shore were quite unconscious that they had been exhibited inverted in the air, and in distorted and grotesque forms.

Our knowledge of the meteorological changes that are taking place in the upper regions of the atmosphere is limited and imperfect, yet there have been some facts noticed by observers relating to those regions which have a bearing on our present subject. In some mountainous regions the tension of vapour, as indicated by the dew-point, has been ascertained by Kaemtz at considerable elevations, and also, at the same time, over the low countries immediately contiguous, and it has been found that the tension generally indicated an increase in the quantity of vapour during the daily rise of temperature. But at a certain stage of its progress the increase was occasionally stopped, and the reverse process took place, as the tension

became less.* These observations show, that while evaporation from the surface was increasing with increasing temperature, some cause came occasionally into operation which checked and even reduced the tension of vapour at certain elevations; and frequently a second increase took place at such elevations, after a reduction, exhibiting a double maximum tension in the same day. The formation of cloud at the time, and the consequent removal of some of the pressure of the higher vapour on that nearer to the surface, seems alone capable of accounting for these facts.

The day cloud is known to form at various heights, according to the temperature of the air, and it is sufficiently evident that that formation is produced through ascent of vapour from below. But at whatever height the cloud forms, the consequences must be of the nature here pointed out,—incumbent vapour pressure on the lower regions will be reduced; the vapour in those regions will expand more freely and become more rarefied, or its tension will be diminished.

* See page 150.

ESSAY XI.

Rain at Different Elevations.

Much labour has been employed to ascertain what are the quantities of Rain that fall at different heights in the atmosphere, in the same locality. Assuming that the theory of the formation of rain which has been here advanced, is substantially correct, it will be apparent that the relative amounts that fall at various elevations, in a vertical column, will not be the same. When a large quantity is formed within a cumulous cloud and carried to a great height, where, through the expansion of the atmospheric gases, the drops of rain are thrown off laterally to a considerable distance into cold air, they may soon acquire a temperature as low as that of the clear air at the superior elevation;—and should they afterwards, in their fall to the earth, have to pass through warm air fully charged with vapour, the cold of the rain would condense upon the drops some of the vapour, when each drop would be enlarged in its descent. These drops, if collected at different elevations, would obviously, as they approached the earth, furnish larger quantities of water.

But the rain from a cloud may fall not beyond, but within the warmth of that cloud, and consequently may itself continue warm for the elevation, as long as it remains within the cloud, and the part of the atmosphere below the cloud and nearer to the earth, may be sufficiently dry to cause evaporation to take place from the surface of each drop of rain whilst it is falling. Each will then become smaller as it descends, and the whole of them will successively constitute smaller quan-

tities of water the nearer they approach the earth, as could be shown if rain gauges were placed at various heights to receive it. It is, indeed, apparent that in this way some rain that has been produced in the higher regions of the atmosphere, often wholly evaporates during its descent, whilst other rain may bring to the earth only a small part of that which was falling at a great height.

Let us suppose a wind to blow against the sloping side of a ridge of land, rising to a height of say 1,600 feet, and suppose this wind at the level of the sea to have a temperature of 57°, and a dew-point of 52°. It is evident that the part of the wind near the surface would pass over all the lower portion of the slope and up to 1,500 feet as a dry wind, neither producing rain nor forming cloud;—because the air from the low level would not be sufficiently raised and cooled in its ascent to condense any of the vapour which it contained. But when this air was driven to the top of the slope, it would be sufficiently cooled by expansion to form cloud. Under these circumstances, rain might form near the top, whilst it would be fine weather over the lower part of the slope.

But suppose the wind at the surface to have a dew-point of only 4° instead of 5° below the temperature, and it will be perceived that the cloud would then be formed, not only near the top, but down to a level lower by 400 feet; and any rain that might fall from the cloud, might alight on the whole of the slope that was between the top and 400 feet below it. If the dew-point were only 3° below the temperature at the surface below, cloud would begin to form 700 feet lower than the top, and generally in such a wind the nearer the dew-point approached the temperature at the level of the sea, the lower would cloud form against the slope of the hill, from which rain might fall. As the dew-point at the surface, however, is seldom as high as the temperature, but in general considerably below it, it follows that rain will seldom fall from a cloud that is near the surface, over either the sea or the low ground.

But it will often fall from a small height above the sloping sides of rising land, and more especially against the higher parts of such land. Where rain is produced near the level of the sea 50 days in the year,—it may occur against a height of 1,000 feet 100 days, and at a height of 2,000, 150 days. Hence in many places it rains more frequently against the sides of hills than on the sea shore, or the low intervening ground.

Cloud is however formed and rain falls from it, not merely in that part of the atmosphere that is near the surface of the earth, but also at very considerable heights above it. As we ascend from a low level in the open atmosphere, the dew-point ordinarily approaches nearer to the temperature, until at some moderate, though varying, height they often are the same, when cloud begins to form. And a whole column of air so circumstanced, being carried against the slope of rising land, would be all raised, and the upper as well as the lower part of the column would be cooled by the diminution of incumbent pressure, and that portion of the atmosphere which had its dew-point nearest to the temperature, would have vapour within it converted into rain the earliest; so that even over hills rain may be produced at a considerable height above the surface of the ground. The rain which descends on low lands, as well as on the sea, generally comes from a considerable height in the atmosphere; this is known and acknowledged, whilst it is commonly supposed that that which falls against the sides of hills is always produced near their surfaces; this, however, is not necessarily the case, as the rain there, as well as in other parts, may be formed at considerable heights above the surface. The actual heights at which clouds are formed by ascending streams of moist air, are determined by the degrees of saturation of the different strata of the atmosphere; but when a portion of the lower air is taken to a great height, and there allowed to expand in full proportion to the diminished pressure, a moderate degree of saturation near the surface is

sufficient to produce cloud. Winds, however, when they blow against the sides of hills, often convey portions of air saturated in various degrees at different elevations, from low levels to superior heights, and thus produce clouds and rain at various elevations.

Again, the whole of a thick stratum of air may, with due relation to the height of each part, be so fully saturated with vapour as to permit the cold consequent on a small rising to form cloud in nearly every part of it: or, the cloud may form first at the top, or at the bottom, or in any other part of the stratum, according to the degree of saturation of the part, and the cold of the elevation that is attained; and each elevation, as has been shewn, is liable to be temporarily saturated by conversion of floating cloud into vapour. It is obvious too that, while a wind is blowing, each part of the land will not receive all the rain that is formed directly over it,—but only that which descends to it, the remainder being carried on by the wind;—and in hilly countries it may, and indeed does commonly, fall against the rising ground. The higher ground thus frequently receives not merely the rain which is formed directly over it, near the surface, but also, successively, parts of that which had been formed over lower levels, but at greater distances from the surface: and the highest ground may consequently receive portions of what had been formed at different elevations above all the lower levels.

It may possibly be supposed, from what has been here advanced, that when a stratum of saturated air is moving over flat ground, the motion alone of the air would not produce cloud, or rain, but that it required to be forced up a hill to produce such a result;—this, however, would not be correct. The atmosphere, in moving over the surface of the globe, presses on the lowest level with a certain force:—this creates friction, which retards the advance of the lowest part of the air, and the retardation is successively communicated, though in inferior degrees, to the higher parts. The less retarded

and higher parts, therefore, climb and pass over the lower until the air which in a particular locality constituted the lowest stratum, attains a considerable height, where it expands and acquires the temperature belonging to the superior elevation, when rain may be produced. Against the sloping sides of rising ground, both the causes that have been here pointed out are in operation during a wind, producing a rise of the air through its being forced up a hill by its horizontal motion, and also through retardation in the lower part by friction against the surface, and both of these causes contribute to the production of rain in such situations.

A direct line drawn through the atmosphere from the western edge of Lancashire, to the top of the ridge which separates that county from Yorkshire, would be, say about forty miles in length. Now, if the land rose parallel with that line, from the operation of the causes just explained—rain coming from the west would, on an average of years, fall along the line in quantities increasing with, and determined by, the elevation of each part. The quantity might be, say 20 or 30 inches in the year at the western edge, and 40 or 60 inches, or some other quantity, at the highest part, the intermediate parts having quantities proportioned to the elevation of each part. That we have not such regularly increasing quantities of rain now actually falling along the line, is attributable to the irregularities of the ground, and even to the trees and buildings, which produce partial obstructions, cross currents and eddies, varying to all conceivable extents. But the surface of the earth at the various levels, as well as the sea, has, as has been already explained, a supply of rain which is produced by a different cause, namely, the daily heating of the air, near the surface, by the sun. This, however, has been fully treated of in former papers.

In stating that much rain frequently falls among hills, it is not intended to intimate that the quantity goes on increasing with the height of the hills, however lofty they may be. The

probability is, that over each rising land the quantity of rain increases up to some certain height—above which it diminishes, until at some elevation no rain will fall;—these heights will vary according to the temperature and dew-point of the locality. Where both temperature and dew-point are high, a strong ascending current may be produced, and the maximum quantity of rain may fall at a considerable elevation: where both are lower, the maximum quantity may be found at a much lower level. The greater or less continuity of the rain will also have its degree of effect. Continuous rain warms the atmospheric space up to a height greater than an occasional shower does, and that warmth may prevent condensation taking place from new supplies of vapour until they attain a higher level; whilst a large part of the vapour which a sudden cool and moist wind may bring, may be condensed at a moderate height, if the locality has not been previously warmed by condensation. When the atmosphere is fully saturated with vapour and the dew-point is at 80°,—as has been already stated, the vapour constitutes about one forty-eighth part of the whole, whilst with a dew-point of only 32°, the vapour is only one two hundred and fortieth part of the atmosphere. Now if from any cause air with a dew-point of 80° should be raised to a height that will reduce its temperature below that degree, it will evidently have a part of its vapour condensed. And if this air should ascend high enough to be cooled down to 32°, it must have all its vapour between the 48th and the 240th part of the atmosphere, converted into water to fall as rain. It is evident, therefore, that the greater part of the vapour which ordinarily exists in ascending moist air, must be condensed at some moderate height, seeing that but little of it can, in an aëriform state, pass into the very cold elevated regions of the atmosphere. The ascent to the upper regions being accompanied by decrease of temperature, whatever point of tropical heat at the surface we start from, the constant decrease of temperature will at last find the

[illegible] condensation, and therefore within some limit the cold will condense nearly all the vapour contained in the air, and above that limit but little rain can fall, because there is but little vapour left to produce it. If rain began to descend as soon as condensation of the vapour commenced, it would not be difficult, in a given state of the atmosphere with relation to the temperature and dew-point, to determine at what heights the various quantities of rain would be formed; but when it is formed, heat is liberated and an ascending current is produced, and we do not know what will be the temperatures and ascending forces of the currents, although we do know that as the air rises it must be under the influence of laws of expansion and cooling, and that the vapour which it contains is under those laws of condensation, and of liberation of heat, to which it is subjected in our mixed atmosphere.

The ridge of the Yorkshire hills, already alluded to, may be considered as 1,600 feet high. The ridge of Helvellyn may be taken at 3,000 feet; Ben Nevis as 4,000 feet; and the highest ridge in Norway, as 8,000 feet in height. Now let us suppose the same wind to blow against the western side of all these ridges, which wind near the surface of the globe has a temperature of say 57°, and a dew-point of 52°, a kind of atmosphere not uncommon in the summer of this part of the world. When it rose to a height a little above 1,500 feet, it would average a temperature of 52°, the same as the dew-point, and, when passing over the Yorkshire hills, would form a slight cloud. In ascending Helvellyn it would, at the top, have a temperature of say 47°, and the vapour which it had contained between the dew-point at the surface and the temperature at the top of the mountain would be condensed, and some of it might fall as rain. The same wind, in climbing Ben Nevis, would acquire a temperature of less than 44°, and vapour would be condensed until the dew-point was reduced to that degree. In ascending the mountains of Norway, the freezing point would be reached at a height of 7,500 feet, when

all the vapour which the wind had contained between the dew-point of 52° at the surface and of 32° at the height of 7,500 feet, would be condensed, and might fall as rain. Now the atmosphere at 52°, with a dew-point at the same degree, has vapour amounting to say a 120th part of the whole, whilst an atmosphere with a temperature and dew-point of 32° has vapour to the amount of only a 240th part, or not more than half the first-named quantity. So that, omitting the influence of heating by condensation, one-half of the vapour which the supposed atmosphere contained when at the level of the sea, where it would appear a clear and dry air, would be condensed, and might fall as rain, when it ascended to a height of 7,500 feet. And any further condensation of the remaining vapour that might take place at a greater height, would be followed by congelation; and snow, instead of rain, would be produced.

Mr. Miller, in a paper read to the Royal Society, on May 18, 1848, gives a number of important meteorological facts relating to the Lake district of Cumberland and Westmoreland. The statement of the falls of rain that take place in many parts of this locality are very valuable, on account of the different heights of the parts above the level of the sea where the rain gauges were placed, and the particular shape of the face of the country. For a long time it had been known that the fall of rain became greater, as the ground rose from the low level of Lancashire to the top of the ridge which separates that county from Yorkshire; and it appears that the same general fact is, to a certain extent, observable in Cumberland, Mr. Miller having found that the fall was small at Whitehaven and other places in the low country near the sea, compared with that which took place up the valleys and on the mountains of the interior country. And that gentleman, after stating many facts, attempts to exhibit a law which determines that the amount of rain shall increase up to a certain height, and decrease above that height. He says—"It seems probable

that in mountainous districts the amount of rain increases from the valley upwards to an altitude of about 2,000 feet, where it reaches a maximum, and that above this elevation it rapidly decreases." Now, although the facts thus given are important in themselves, and afford a certain degree of countenance to the hypothesis advanced; yet neither the facts nor the reasonings founded on them are sufficient to warrant the general conclusion drawn from them by Mr. Miller.

A return is given of the quantities of rain that fell in twenty different places in Cumberland in the four years 1845-6-7 and 8; and of these places we may, in the first instance, take three as a sufficient number to show how far the facts harmonize with the law thus laid down, namely, Whitehaven, Wastdale-head, and Seathwaite—the first being on the sea-coast, the second, inland, at the mouth of the mountain pass of Sty-head, and the third, beyond that pass, and in the valley of Borrodale. In these three places there fell in the years named the following quantities of rain, namely:—

	At Whitehaven, 90 Feet above the Sea.	At Wastdale Head, 160 Feet above the Sea.	At Seathwaite, 240 Feet above the Sea
	Inches.	Inches.	Inches.
In 1845	49.207	108.55	151.87
" 1846	49.131	106.93	143.51
" 1847	42.921	96.31	129.21
" 1848	47.344	115.32	160.80
Mean	46.589	106.60	145.63

Now, the differences in the heights of these three places are not very great, but the differences in the quantities of rain that fell are enormous—quite enough to warrant a suspicion, that the very large amount that fell at Seathwaite is not attributable to the height of that place above the sea. But in addition to those three places, there is the Pass of Sty-head, 1,290 feet high, situated between Wastdale-head and Seathwaite, on which a rain-gauge was placed; it is, however, so cold there in the winter, and the gauge is so much affected

by snow and ice at that season, as to prevent reliance being placed on it during that portion of the year. Yet we may compare the quantities of rain that fell in the summer months only at Sty-head and Seathwaite, as given by Mr. Miller—they are for the six summer months of 1848—

	Inches.
Seathwaite, 240 feet above the surface of the sea	68.96
Sty-head, 1,290 feet above the surface of the sea	60.35

Here we find no increase in the quantity of rain that falls above 240 feet of height where the gauge is placed in Seathwaite. On the contrary, the quantity is greater there than at Sty-head, 1,050 feet above it. This fact furnishes rather strong presumptive evidence, that the quantity of rain that is received in a gauge, at any particular elevation, is not proportioned to the height at which the gauge is placed.

In comparing the quantities of rain that fall at various heights, including great elevations, it is obviously necessary to compare them during the summer months alone, as has been done when comparing Seathwaite and Sty-head Pass; and the facts that are principally relied upon by Mr. Miller, and from which he draws his general conclusions, are the quantities of rain that fell in twenty-one months in 1846 and 1847 in six places, namely:—

			Inches.
The Valley (Wastdale)............	160 feet above the sea,		170.55
Sty-head..............................	1,290	"	185.74
Seatoller..............................	1,344	"	180.23
Sparkling Tarn	1,900	"	207.91
Great Gable	2,925	"	136.98
Scaw-fell	3,166	"	128.15

But these facts, although they countenance the hypothesis advanced, do not afford conclusive, or even strong, evidence upon the subject. The Valley we see, 160 feet high, has 170.55 inches; whilst Seatoller, 1,344 feet high, and consequently 1,184 feet higher than the Valley, has only 180.23 inches, not 10 inches more of rain; whilst Sty-head, 54 feet below Seatoller, has 5½ inches more of rain than that place.

There is another place noticed by Mr. Miller, called Brant Rigg, 500 feet high, between the Valley and Sty-head, which received 12½ per cent. less of rain than the Valley, which is only 160 feet high, showing that here less rain fell in the higher than in the lower parts; and there are other anomalies that might be pointed out. It is, however, such a place as Seathwaite that shows, in the most palpable and striking way, that the amount of rain which is received by the ground in a particular locality is not determined by its height. Seathwaite, *not more than 240 feet* above the sea, receives more rain than any of the places having a greater elevation; and Mr. Miller candidly admits that he is "unable to offer any satisfactory reason for the great excess of rain at Seathwaite over all other valleys."

In order to account for the great and unequal quantities of rain that fall in different parts of this district, it is necessary that we should remember the causes which determine the formation of rain at various heights in our atmosphere, as already explained. The following figures will show the heights at which vapour would be condensed under certain circumstances; that is to say, with the air and dew-point of the vapour at the surface both at 59°, when the tension of vapour is equal to half an inch of mercury, the wind at the time blowing up a valley and sloping sides of a mountain. The lowest stratum of air being 59°, the temperature and dew-point would be reduced at a height of—

300 feet	to	58°	1,200 feet	to	55°	2,100 feet	to	52°
600	"	57°	1,500	"	54°	2,400	"	51°
900	"	56°	1,800	"	53°	2,700	"	50°

And all the vapour that existed in the air between the dew-points of 59° and 50° would be successively condensed by the time that the air and vapour reached the height of 2,700 feet, and rain, the product of that amount of condensation, would be produced at the various heights as the cooling proceeded.

There is, however, a second process going on under such

circumstances as those just described, which, as it modifies the first, it is necessary again to notice. When condensation of vapour takes place heat is liberated, and the temperature of the locality is raised. The gases in the part are then warmed, and they expand and ascend to a greater height, where they are further cooled, and where they condense more vapour. So that the vapour is condensed in the first place by the atmospheric mass being forced up the inclined plane of the land, mechanically, as a wind—and, secondly, by the ascent produced by the heating power of condensing vapour; and whilst the mass of air and vapour is carried up from both these causes, it is moving forward horizontally as a wind. In the locality, then, the wind moves mechanically towards the upper part of the valley, whilst from the heating effects of condensation, it is ascending above that part; the condensing vapour will therefore be liable to be carried above the highest part of the land, and the greatest quantity of rain may fall beyond that part. And, further—after the vapour has been condensed, and the rain formed at a certain considerable height in the atmosphere, it has to descend from that height, and will be liable, while so descending, to be carried forward horizontally by the wind, and will reach the earth at a part beyond that over which it was formed.

Now, to apply this general statement and reasoning to the case under consideration: let us suppose that air saturated with vapour of the temperature of 59° passes from the sea-coast, near Ravenglass, towards the mountains as a south-west wind. When this wind reaches land 300 feet high, it will be cooled by ascent 1°; and will have all the vapour condensed that is contained between a dew-point of 59° and one of 58°. When it reached land 600 feet high, 2° of vapour would be condensed; 900 feet 3°, and so on in succession, 1° more for every 300 feet of height up which the air was forced mechanically. Add to this the vertical ascent produced by heat from condensation, and the actual progressive motion of the condensing vapour

will be intermediate between the two. Supposing the two forces to be equal, the mass would proceed forward, ascending at the angle of 45°. Sty-head Pass is 1,290 feet high—the atmospheric mass, therefore, when it reached Sty-head would be cooled, say 4°, and it would be liable to be carried over the head of the Pass, rising at an angle of 45°. We might therefore expect, from the known laws of condensation of vapour, and of the action of wind, that, under the circumstances described, a larger amount of rain would fall beyond Sty-head, than either in the approach to it, or on the top of it; and accordingly it is the fact that a larger quantity of rain falls in Seathwaite, which is a little beyond the Pass, than in any part between Seathwaite and the sea.

In such a locality the saturated air, forced by the rise of the land to ascend, entering the wide mouth of the Valley, which *contracts in breadth as it proceeds, rushes through the narrow* gorge in the upper part, and over the top of the mountain pass, with great velocity and force; condensation, therefore, will take place to a greater extent along this particular and comparatively low line, than where the ridge of the mountain is higher by 2,000 feet. The higher parts stop the passage of the wind, which makes its way where there is the least resistance, and this is over the pass of the mountain ridge; and as the horizontal rush of air is here particularly strong, any rain that is there formed, or that has been carried thither, will be liable to be borne forward until the air loses some of its velocity in the comparatively open space beyond the Pass where the rain is likely to be deposited—just as running water deposits sand when it reaches a wider and comparatively still part of a river. In the case stated, the air was supposed to be saturated with vapour, but if it should not be fully saturated, but have a dew-point of, say 1° below the temperature, the only difference would be that condensation would not begin until the mass of air climbed 300 feet,—a dew-point of 2°—600 feet; and other dew-points in proportion.

We see, then, why the largest quantity of rain should fall in Seathwaite when a south-west wind blows from the sea over Sty-head, as Seathwaite is favourably placed to receive much of the rain brought by that wind; but other winds blow in this district during a large portion of the year, and as much more rain falls at Seathwaite than in any other part, these other winds must, we presume, also bring rain to that place. To see how this is effected, we have to examine the shape of the neighbouring country, and particularly in the directions from which rainy winds come; and we may perhaps obtain a tolerably good idea of what that shape is from an account given in Hudson's *Guide to the Lakes.* In this work, page 118, it is said—"I know not how to give the reader a distinct image of the main outlines of the country, more readily than by requesting him to place himself with me in imagination upon some given point, let it be the top of either of the mountains, Great Gable or Scaw-fell; or rather, let us suppose our station to be a cloud hanging midway between those two mountains, at not more than half a mile's distance from the summit of each, and not many yards above their highest elevation: we shall then see stretched at our feet a number of valleys, not fewer than eight, diverging from the point on which we are supposed to stand, like spokes from the nave of a wheel." Now, this imaginary point in the air is nearly over Sty-head Pass. The writer then proceeds to describe Langdale, the Vale of Coniston, the Vale of Duddon, Eskdale, Wastdale, Ennerdale, and the Vale of Crummock-water, and Buttermere. And he goes on to say, that "such is the general topographical view of the country of the lakes; and it may be observed that, from the circumference to the centre, that is, from the sea or plain country to the mountains specified, Great Gable and Scaw-fell, there is in the several ridges that inclose these vales, and divide them from each other—I mean, in the forms and surfaces—first, of the swelling ground, next, of the hills and rocks, and, lastly, of

the mountains—an ascent of almost regular gradation from elegance and richness to their highest point of grandeur and sublimity." Nearly all these eight valleys, in the low flat country, present wide openings to receive any wind that may be blowing towards them—they contract towards the centre where the ground rises; and the wind, whether it blows from, say, the south, south-west, the west, or the north-west, will force its way over the lowest points of the central chain, and be disposed to discharge rain on the country a little beyond those points. Borrodale is just in this situation, and must therefore receive rain from every moist wind that comes from a southern or western quarter, in the way that has been described; and Seathwaite seems to be in that part of Borrodale which receives the largest quantity of rain.*

The large fall of rain in this village is then to be considered a result of various rainy winds blowing up the different valleys, and particularly those which lie to the south and west of it, as those winds force the mixed masses of air and vapour to rise to the lower parts of the elevated ridges that are at the heads of these valleys. At or above these parts the vapour is largely condensed, and the rain that is formed is carried forwards and deposited on the low ground beyond the ridge; but though deposited there it evidently descends from a great height.

Speaking in general language, it may be said that the largest quantities of rain fall from warm and moist atmospheres, as such atmospheres contain the largest quantities of aqueous vapour; and the rain is formed by the condensation of a part of the vapour, at a height dependent on the elevation that is attained by the atmospheric mass when forced to ascend, and the difference between the temperature and the dew-point

* Since this was written, another part that is contiguous has been found to receive more rain. It is stated that the quantity of rain that fell annually at Seathwaite, on an average of five years, 1845 to 49, was 142.19 inches. In 1850, it was 143.96 inches, whilst it was computed that at Sprinkling Pass no less than 189.49 inches fell.

in that mass. If the rise of the land is great and abrupt, approaching a vertical cliff, the larger part of the rain might possibly fall on the low ground in front of the cliff, the mass of air being unable to pass over it, until such a height was attained as would leave little uncondensed vapour existing in the air. In such a situation it is evident, that one gauge placed at a low level in front of the cliff, might receive more rain than another fixed at any height above it. And it is equally clear, that when rain is formed whilst passing over an elevated ridge, that rain might be received either in a gauge placed beyond it, only a little lower, or in one not farther beyond it, but fixed in a deep valley below, as is, in fact, the case with the gauge at Seathwaite. We may therefore conclude, that in a country containing lofty mountains and deep valleys, with much irregularity of surface, the height of the gauge into which rain falls does not indicate the elevation at which it was formed—that elevation being determined by the laws of cooling of the aqueous vapour that is contained in our mixed atmosphere, whilst the vapour is diffused through the gases.

The following account has been furnished to me of the

Fall of Rain in a year at Cuchullin Lodge, in the Isle of Skye, being the Mean of the Two Years, from Sept. 1, 1849, *to Sept.* 1, 1851.

	Inches.		Inches.
January......	18.3	July	5.1
February....	12.1	August	10.1
March	9.3	September...	8.8
April.........	5.4	October	18.2
May	5.0	November ...	15.7
June	12.7	December ...	11.4
		Year......	132.1

ESSAY XII.

On Regions of Calms and Rainy Seas.

There are certain localities which have been pointed out where vapour is condensed to a large amount, and where ascending atmospheric currents are consequently created, towards which winds blow from certain distances. These localities are scattered irregularly over the surface of the earth, determined, evidently, by the situations of mountains;—and many of the winds that are thus produced, pass over the sea where there are no elevations to obstruct them, and go on until they reach mountains. In some cases these winds may be traced backwards from the mountain area of condensation to the neighbourhood of a part over the sea where a calm atmosphere generally exists, beyond which calm another wind is found to blow in a different direction; and this second wind, if followed to its termination, will be discovered always to end in another region of condensation, near to or over elevated land. These circumstances leave us at liberty to infer that the condensation carried on at the terminations of the winds, drew air towards them from certain distances only, and left an intermediate part undisturbed, because that part is just equally affected by each contiguous wind. This being admitted, it would follow that the state of calm in the intermediate part is due to the equality of the forces exerted on the two sides which were drawing the air from it in opposite directions. There may be three or more localities in which condensation is taking place at the same time, all having a tendency to

draw air from a particular part, but in which part the different forces are so equally balanced as to leave an intermediate space undisturbed by their action; and this space would be, as compared with the lines along which the winds blew, a region of calms.

Now the actual situation of a portion of the Atlantic Ocean, not far north of the equator, resembles this hypothetical case. It is thus described by one writer:—"Between the meridian of Cape Verde and the easternmost of the group of islands which bear that name, there is a zone of 350 miles in breadth, in which there is almost no wind, except of the most variable description. Ships have been known to be here becalmed for whole months."* This zone extends southward, near to the equator, but it changes its place to a considerable extent, north or south, with the passage of the sun from one tropic to the other, and its breadth diminishes as it approaches the American side of the Atlantic, the trade winds from the two hemispheres joining there, and blowing as an east wind. Milner speaks of this part as follows:—"In the basin of the Atlantic the zone of the trade winds, which generally occupies from 2° to 10°, becomes broader, and their direction more easterly, as the coast of America is approached, the breeze blowing to the very shore. In the region of the tropical calms, lying between that of the north and south trade winds, day after day is often passed without a whisper of wind, and the ocean has no movement but that of a long huge swell. But for the occasional occurrence of short squalls, the passage of this region would be almost impossible to sailing vessels."† And Malte Brun says:—"On the confines of the trade winds in the Atlantic Ocean, between the 4th and the 10th degrees of north latitude and the 330th and 365th of longitude from the island of Ferro, there is a space of sea where the navigators find perpetual lightning, with rains so frequent and so copious that the track has been called the rainy sea."‡ This

* Hutchison, p. 316. † Milner, p. 334.
‡ Malte Brun, vol. i., p. 389.

description does not accord strictly with Hutchison's. The region of calm has, indeed, a motion, because the influences which determine it travel north and south with the sun. And in our summer, when the north-east trade wind blows with inferior strength, the calm extends westward, towards the Caribbean Sea. But the proper region of calm has on its northern side the north-east trade wind, which blows from near the Canary Islands to that part of the coast of South America that is north of the equator, and the West India Islands, whilst on the southern side it has the south-east trade wind; and on a third side it has the western wind that blows into the gulf of Guinea, the calm space on its western side *sometimes terminating in* a point at a considerable distance from the American coast. It thus appears that this region of calm forms an irregular triangle, and within it we presume that the air, as has been described, is generally undisturbed, or without any regular motion as a wind, because the forces that draw the air on its three sides balance each other. From this state of things it would seem to follow, that the air being drawn from the outer portion of this triangular space to feed the regular winds, its density in that part near the surface of the globe must be somewhat reduced, when the upper air will have a tendency to descend. But the great mass of the stagnant air in the central parts of the triangle, as it rests on water, and is warmed by a tropical sun, will, in no long time, be fully charged with vapour up to a considerable height,—the sky over it will be generally hazy and cloudy, and the area warm and moist, and ready to produce rain in the central part.

Humboldt says that a similar sluggish state of the atmosphere is experienced on the western coast of America, between the 13th and the 15th degrees of north latitude and 103 and 106 degrees of west longitude, during the months of February and March; and when off the Gulf of Panama, April 17th, the Hon. P. C. Scarlett describes a part like the rainy sea of

the Atlantic.* Here no wind was felt; that which blows along the western coast of South America turns westward before it reaches the equator, and the great tropical Pacific trade wind commences only at a considerable distance from the land, that is, much farther westward; whilst on the eastern and northern sides of the locality there are ranges of mountains, forming a barrier to the free passage of the atmosphere.

Bennet says of this neighbourhood,—"The steady north-east trade winds had left us at the 7th degree of north latitude, and say 110° of longitude, and the south-east passed but rarely across the equator, consequently this was a kind of neutral ground in which all the elements indulged. The winds were variable,—squalls and calms were frequent, whilst heavy rains rendered the process of boiling our oil both protracted and dangerous." In this locality, like that off Africa, in the Atlantic, the air is not regularly borne away either by the north-east or the south-east trade wind; the part is therefore a region of calm, in which evaporation is left to fill the atmosphere with vapour. But this calm region, though it may penetrate far into the Pacific, does not extend across the whole of it. As in the Atlantic, the two trade winds from the north and the south of the equator appear to approach each other, and at last join and become an east wind.

There are other parts where a similar state of the atmosphere is found at particular seasons, where winds produced by continued rains that fall in distant parts, do not exercise a constant influence and create a trade wind,—such as the Bay of Bengal, the China Sea, and the West India Islands. Between the termination of one monsoon of the Indian Ocean and the commencement of the other, a period of calm intervenes in the eastern seas, when the atmosphere gets into a state similar to that described as generally existing over the rainy sea of the Atlantic. The air on these seas becomes

* See page 67.

stagnant, and evaporation goes on until the atmosphere is saturated with vapour, when disturbance takes place in some part of them sufficient to produce an ascending current of air, on which the saturated portion of the lower region is carried to the higher, when condensation becomes more energetic, and a tornado or typhoon takes place, during which the vapour is rapidly condensed, and it falls as a deluge of rain.

In the months of July and August, a period when the whole northern hemisphere is much heated by the sun, and when there is no general strong wind blowing from that hemisphere towards the equator, the air about the West India islands becomes highly saturated with vapour. Under such circumstances, a hurricane commenced near Antigua on the night of the 1st July, 1837, which may be taken as a specimen of what frequently occurs. Captain Seymour, when speaking of its beginning, says that he "observed near the zenith a white appearance of a round form, and whilst looking stedfastly at it, a sudden gust of wind carried away the top-mast and lower studding sails." The round white appearance was doubtless a cumulous cloud. On the 2nd August of the same year, in another situation, the *Water-witch* was caught by the skirts of a similar storm, the wind blowing in squalls from the west and north-west till the evening, when, says Captain Newby, "a calm succeeded for about ten minutes, and then, in the most unearthly screech I ever heard, the storm recommenced from the south and south-west." A third hurricane for the year occurred at midnight on the 18th August, when, "after blowing from the north, in an instant a perfect calm ensued for an hour, and then, quick as thought, the wind sprung up with tremendous force from the south-west, no swell whatever preceding the convulsion." These hurricanes, it will be observed, occurred at a time of the year when there is no continuous wind in the part, such as the trades, and therefore, when the sea had had time to send an abundance of vapour into the atmosphere; and although there had been some

disturbance in the air before the last-named storm, probably on account of the contiguity of islands, yet in its fury the great rush of air came, not from the north or east, the usual quarters from whence winds blow in this locality, but from the west and south, the quarters where the largest amount of vapour was likely to be accumulated; we may therefore conclude that the hurricane was produced by condensation of the vapour that had been recently accumulated in a comparatively stagnant atmosphere.

Between the north-east trade and the south-west return wind of the Northern Atlantic, there is also a space which is generally found to be without continuous wind, and where, consequently, calms and variable winds prevail. When the sun is on the northern tropic, evaporation goes on here during a calm until the dew-point is raised nearly to the temperature, and the part approaches to the state of a tropical region of calm that is occasionally disturbed by storms.

Similar storms are frequently experienced near the Mauritius in January and February, being the corresponding season for great evaporation in the southern hemisphere. The courses which they take, or the paths they traverse, are interesting subjects to navigators, and attempts have been made to show that they move in accordance with a regular law, but on this point we require further information. Colonel Reid has bestowed much labour on this locality, as have Redfield and Espy on the storm regions of the West Indies, but we stand in need of further facts, and especially want information respecting the hygrometrical state of the air, to enable us to judge of what is taking place in such parts. But it may be said that the tornadoes of the Bay of Bengal, the typhoons of the China Sea, the storms of the Mauritius, and the hurricanes of the West Indies,—all take place under circumstances that are essentially the same. The air is in a comparatively stagnant state before they begin, and it is loaded with vapour, shewing that no continued wind had taken the

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vapour produced by evaporation in the part to any distant area of condensation; it had, therefore, accumulated in the locality until it was carried up by the tornado and condensed into rain. But, unlike the condensation which takes place against elevated land, no continuous wind follows these storms, as generally, in a moderate time, they are succeeded by calms.

It is not, however, clear that this is always the case, particularly with the tornadoes that arise in the rainy sea off Africa, as these sometimes appear to produce a wind that blows from a great distance to feed the ascending current. "The Harmattan" blows from the desert of Northern Africa, across the Atlantic coast, extending from 15° of north to about 1° of south latitude; this wind, therefore, blows towards the rainy sea of the North Atlantic, which is off Africa. It prevails generally in the months of December, January, and February—the time when the sun is far south and the southern hemisphere is fully charged with vapour, and when the rainy sea extends near to the equator. There seems, therefore, reason to presume that when the harmattan blows from the African desert, a tornado over the rainy sea has created an ascending atmospheric current, of such extent and strength as to cause air to press from the adjoining land of Africa towards it, and this air may constitute the wind that has been named, which sometimes blows from the desert to this part of the ocean. The tornado is irregular in its times of occurrence, and so is the wind, and the direction of the wind is palpably towards the locality of the tornado: the only point that remains to be cleared up, in order to show the connection of the two, is, whether they exactly coincide in time? I know of no attempt having been made to ascertain this fact,—nor is it likely to have been inquired into excepting by those who sail between Africa and Brazil, and they are not persons to furnish information on such a subject. Some of the steam vessels which now traverse the

tropical parts of the Atlantic will, however, have to pass near the locality where the harmattan may be presumed to approach the tornado, and, from persons conducting these vessels, information on the subject may possibly be obtained.

Where these storms are entirely local, a large mass of air and vapour must be taken by them to the upper regions of the atmosphere to be discharged on the adjoining part, and to press upon it with additional weight. And as this pressure will take place when other air is ascending in the vortex, that which is pressed up may flow back from above and return to the vortex. In this way a kind of vertical ring may be formed in the atmosphere, the ascended air flowing over to adjoining parts, and then, in due time, descending like a wheel and returning to feed the ascending current. But it is obvious that the air so descending would be dry—having been deprived of its vapour by the cold of the elevated region into which it had been carried; condensation in the vortex would therefore soon cease. This view will enable us to account for the sudden cessation of some of the fierce storms that occur in these parts. If vapour were supplied continuously near the surface and from greater distances, to feed the ascending current, it would seem that the storms of these parts could not terminate so suddenly as they frequently do.

We have therefore to conclude, from the various facts that have been collected, that, generally, these regions of calms are at the time of calm beyond the influence of any of the great areas of continued condensation that exist on the land, or of the winds that they create;—and that evaporation goes on within the regions until the atmosphere is saturated with vapour, when condensation takes place in the locality, and the vapour is converted into rain.

It is within certain parts of the tropical seas that these regions have been mostly found, because, while no regular wind exists there, the sun evaporates water with great energy, until the air is saturated. But the same processes really take

place in extra-tropical latitudes at periods when the sun exerts great force. In the summer season, over the Northern Atlantic, storms similar in their character sometimes occur; but as the atmosphere in these latitudes is not so highly charged with vapour, as it is in the tropics, the vacuum created by condensation is not so considerable, and the ascending current does not there attain so great a height. Within the tropics, the ascending column may reach such an elevation as will make the difference between its temperature and that of the adjoining air which remains undisturbed, very great, when the lightened column will be pressed up rapidly to a great height, where expansion by the reduction of incumbent pressure will lower the temperature enough to convert the drops of rain into hailstones, sometimes of large size. In the temperate latitudes the storms are less fierce, and though rain is often carried so high as to be frozen into hail—the hail is of a moderate size, and the thunder and lightning, that frequently accompany it, are less awful than within the tropics.

But it is not over the sea alone that such storms take place, as they may be produced wherever a sufficient quantity of aqueous vapour is sent into the air by evaporation. This may occur over low land, or even against the sides of mountains, a temporarily saturated locality being the only requisite essential to their production. There are certain parts on land where they are produced periodically, and due examination would, no doubt, shew that when they occur in such parts, air more or less stagnant for a time has allowed evaporation to proceed until it was sufficiently charged with vapour. There are other places where little storms resembling the large ones occur daily. On the west coast of America, near the equator, and in the island of Jamaica, near Kingston, we are told that thick clouds form daily, a little after noon, against the sides of mountains, when heavy rains fall and loud thunder is heard for a short time. These are, in fact, tornadoes in miniature—

but they are confined in the locality by the daily solar influence on the adjoining sea, and the particular elevation of the land.

Such storms, however, cannot occur where the great trade winds blow. In these winds the vapour is regularly carried by the moving mass of air, from the place where it is evaporated, before enough is accumulated to saturate the air. In the Pacific Ocean, at a certain distance from the tropical American coast, navigators speak with delight of the trade wind that is there found. The ship is said to be borne along by a steady moderate wind, the air being clear by day and the sky bright at night, but it is because far to the west condensation of vapour is drawing the mass of the atmosphere to that distant part before it is fully saturated. The same kind of circumstances is found in both of the trade winds of the Atlantic. From the Cape of Good Hope to St. Helena, and afterwards to the island of Ascension;—and from the Canary Islands towards Barbadoes, but particularly in the eastern parts of these winds, steady breezes and clear skies are found. Even in the stormy south-west monsoon of the Indian Ocean, from say 10° south of the line, to as many north of it, say between Madagascar and the Arabian Sea, there are no storms or very cloudy skies. When any of these winds cross a wide ocean, there is no doubt that the point of saturation may be approached before the area of condensation is reached. But it would appear, from numerous facts observed, that the higher the temperature and the more complete the saturation where the condensation takes place, the more rapid is that condensation and the stronger the wind. The ascending current, in the area of condensation, more or less effectually drains the lines over which the air passes of their vapour, and this draining is sufficient to prevent such an accumulation of the vapour as is found in regions of calm. It is evaporation alone that furnishes the vapour which creates local storms, and also

that feeds heavy rains among mountains;—the great natural operations are the same, the circumstances that accompany them alone differ; and when we obtain the key to those operations, in a knowledge of the laws that govern evaporation of water and condensation of vapour in such a body as our atmosphere, all the modifications that result from those circumstances may be accounted for. And as evaporation is generally taking place at the surface of water to some extent in all latitudes, where, if undisturbed, vapour would accumulate to the point of saturation, we may be assured that, when the atmosphere over the sea is dry, wind is taking the vapour to some other part to be there condensed. Even beyond the tropics, when the air is stagnant, and becomes fully saturated, storms will alternate with periods of calm,—and the locality may be considered as approximating to a region of calm, or a rainy sea, as the stillness of the air or the fall of rain is more particularly noticed.

In the latter part of summer, in Italy, I happened once to be standing on one of the small Borromean Islands in Lago Maggiore. The day was fine, rather warm, and perfectly calm. Looking around at the mountain scenery, my attention was arrested by a dark spot being formed in the previously clear atmosphere, which spot enlarged in size rapidly. On directing the attention of a gentleman, who was with me, to the dark object, he exclaimed—"Ah, we shall have a storm!" As all around, excepting the small cloud, was clear and calm, this seemed strange. But the cloud rapidly increased in size; a slight flash of lightning struck out of it;—it grew blacker, and spread very quickly, until in a short time it covered the whole of that part of the lake where we stood. Rain commenced falling, and soon became a torrent, such as is not often seen in England, whilst winds blew in gusts from different quarters. Shortly the storm moderated, less rain fell, the wind died away, and all became fine again. It appeared

that the whole had taken place within about a quarter of an hour; and after the storm, the atmosphere was evidently less moist than before. It seemed that the atmosphere had been for some time before at rest, and during that time, evaporation from the lake had pretty fully saturated it with vapour. A slight disturbance of the air had probably forced some of it from the lower part up the side of a steep mountain, and caused some of the vapour to be there condensed, and this formed the dark spot I first saw. An ascent of the cloud now took place, and the condensation within it not only produced an ascending current and rain, but spread the cloud, until the lake was covered. The vapour was now carried to a sufficient height to condense much of it, and the stock appeared to be soon exhausted, as the rain ceased, and all became fine again. This was a small specimen of what nature accomplishes on a much larger scale over great oceans.

ESSAY XIII.

On the principal Winds of the Northern Atlantic Ocean, and of the British Islands.

The seasons of the year,—the wet and the dry, as well as the hot and the cold,—are determined by the position of the sun in the heavens, and by the different degrees of influence which that body exercises over the various parts of the earth. When the sun is over the tropic of Capricorn, it heats the whole southern hemisphere, and produces there a certain high range of temperature, leaving the northern hemisphere comparatively cold; but when it passes into the northern tropic, the effects produced are somewhat different. In the former case, the heat acting on the great extent of water which exists in the south, vaporises much of the water, and the whole atmosphere there becomes highly charged with vapour. In the latter, vaporisation is less as the aqueous surface is less; vaporisation is, therefore, different in the two hemispheres, and produces somewhat different effects.

Two important results of the different influence of the sun in the two hemispheres are, the periodical falls of rain in particular localities, and the winds that are consequent upon them. When the sun heats the southern hemisphere, a large amount of vapour is not only produced, but condensed there, thus heating the air by condensation in certain parts of the hemisphere, when colder air flows to these parts, not only from other portions of the southern, but it may be to some extent also from the northern hemisphere: and as at the

same time vaporisation is not equally active in the north, that time becomes the dry season of that part. Cold and dry winds then blow towards the equator over the northern lands and parts of the seas; and from the latter they take up vapour, and convey it to areas of condensation sometimes even beyond the equator. In this way, North America, Europe, and Asia are traversed by dry winds in the winter season, but those which cross the Atlantic Ocean, in warm latitudes, become more or less saturated with vapour, though in the colder parts, when passing over land, they had been comparatively dry.

The British Islands are visited by these dry winds, to a certain extent, every winter, and they are generally the most decidedly dry in the latter part of it, or about the month of March. At this time the great northern wind that blows over Asia and Europe generally extends far westward, reaching the British Islands as a north-east wind. Considerable irregularity occurs in this wind, as sometimes it is feeble and of short duration, whilst at other times it is strong and continues for a comparatively long period. The particular cause of this wind has not, I believe, been explained, nor have its great fluctuations been accounted for: and it probably will be found that the atmospheric disturbances that produce them, are so complicated in their working as to render it difficult to give a clear account of them. Meteorological registers for extended periods, have been carefully examined by many persons, for the purpose of finding evidence of periodicity in the wetness and dryness of the weather over the British Islands, but no satisfactory results have been obtained from such labours. Some meteorologists have indeed thought that they had found sufficient evidence of recurring cycles of wet and dry seasons, but they could not agree what those cycles were, some making them longer and others shorter;—whilst they did not even profess to be able to connect the supposed facts with their causes. The whole subject, therefore, remains in obscurity,—

our knowledge of it permitting us to go no farther than to say that at a certain season, on an average of a sufficiently long period, a particular kind of weather has been experienced, and that in the latter portion of the winter, or in and about the month of March, dry north-easterly winds generally prevail.

But although the operations of nature in producing this kind of weather, at this period of the year, may be so complicated as to render us incapable of following them in detail, it may be possible to obtain a general view of the nature of the operations that are taking place. And if we can, by bringing together scattered facts, become satisfied respecting the nature of the causes that are in action, we may be able to arrange the facts, and make them evidence of the kind of processes that are going on, sufficiently strong to justify us in drawing certain general conclusions. In attempting this, however, we shall be obliged to travel over a large section of the surface of the globe, as the operations that have to be traced extend to great distances, and they produce important effects in parts far from the places where the primary causes are in action. We must recollect that the atmosphere, in which the changes occur, is a body of such a very moveable nature, that when materially disturbed for a considerable time in any one part, it acts strongly on adjoining parts, and the effects are successively propagated to such great distances as to make it difficult to follow the chain of causes to the ultimate effect: this difficulty, however, must be encountered and overcome, if we are to comprehend the phenomena that are under consideration.

In the present inquiry, the first place to which we may direct our attention is the eastern side of the great Cordillera of the Andes, south of the equator, a region of abundant condensation of vapour, which condensation, as has been shewn, must create great ascending currents in the atmosphere, towards which horizontal winds must blow from considerable

distances. This is the case when the sun is over the southern tropic, as at that time an abundance of vapour is produced and supplied from the southern Atlantic and Indian oceans, even as far as the coast of Australia—the south-east trade wind then blowing over these oceans in its greatest strength. In the Atlantic, this wind is found so far south as 30° of latitude, and it extends from that part to the equator. Now, the vapour thus taken up is borne along by the wind to that part of the lofty ridge of the Andes which lies to the south of the equator, where it is largely condensed, and where extremely heavy rains fall. The river Madeira, the greatest tributary of the mighty Amazon,—the Ucayali, and other rivers, collect their waters from this part, extending considerably to the south, and they are at their greatest height in December, which is before the Amazon itself is much swollen by rains. "The rainy season," says Smith, in his account of Peru, "sets in in the upper parts of the country that supply the water of the Amazon about the end of September, but does not commence at Para till towards the end of the year." Part of the northern Atlantic, no doubt, assists the southern in feeding this great area of condensation, as the northern trade wind reaches Brazil while the southern is blowing strongly in December; but it contributes vapour in an inferior degree, as the winter seas of the north, being comparatively cold, do not furnish vapour in equal abundance to the atmosphere as the seas of the south. But the north-east trade wind at this time blows with considerable force near the equator in the Atlantic—over the Caribbean sea, and up the valley of the Orinoco, terminating its course against the eastern side of the Andes, where heavy rains fall. This wind extends in breadth from near the equator to about thirty degrees north, and it blows across the Atlantic from near the Canary Islands to America.

But, in the month of January, as the sun advances from the south towards the equator, it heats the northern tropic and

parts adjacent more highly, and increases evaporation from the seas of those parts. The supply of vapour then becomes successively greater from the northern and smaller from the southern hemispheres, and the area of copious condensation near the Andes moves northward; and as the southern tributary rivers rose to their highest levels, and overflowed their banks, shortly after the sun was on the southern tropic, so, as it passes northward, the northern rivers swell and overflow,—the Orinoco as well as the northern feeders of the Amazon being filled when the southern rivers have subsided, shewing that vapour is now condensed along the great line of condensation of the Andes, more to the north and less to the south of the equator; and the winds which convey the vapour pass less from the south and more from the north Atlantic to the sources of the Orinoco and the Amazon. The northern winds at this time blow strongly over the Caribbean sea and Venezuela, whilst the trade wind in the open Atlantic increases in strength. It would, however, seem that this trade wind could not continue to blow as it does unless air was supplied not merely from adjoining districts, but also from parts more distant; and accordingly it is found that at this time north-east winds prevail to greater or less extent over northern Africa, Spain, France, and Germany.

While, however, wind is blowing over these last-named countries toward the Canary Islands, the comparative warmth of the Atlantic Ocean, in the middle and northern parts, produced to some extent by the great gulf stream that flows into it from the south, is furnishing vapour to the atmosphere that rests upon it, and this vapour is liable to be taken to contiguous countries and condensed in them. Iceland and Norway, in fact, receive a portion of it in thick snows that fall in those countries in the early part of the winter, brought by southern winds; and Ireland, Scotland, and the western side of England have their share of this vapour, and are occasionally supplied with it in abundance in the earlier

part of the year. Thus the middle portion of the Northern Atlantic Ocean, not being cooled down, like the land of the Continent in parallel latitudes, enough to cause the mass of air resting upon it to flow decidedly towards the south, the air over the sea remains exposed to local influences, and the elevated lands of the northern countries become areas of condensation of the vapour which the Atlantic furnishes;—hence we have, frequently, in the last months as well as in the earlier part of the year, in this country, copious rains brought by winds which come from even the southern part of the Northern Atlantic Ocean. These rains, however, are irregular, as the causes which determine the northern winds to blow over Continental Europe sometimes extend their influence to our islands, when the winters are by them made cold and dry.

Were the whole surface of the globe, to the north and north-east of the parts over which the north-east trade wind now blows irregularly, either water or low land, it is probable that a wind would be found blowing constantly between the present locality of the northern tropical trade wind and the British Islands, and the whole would be one great wind blowing from Western Europe over the Atlantic to tropical America. This, however, seems to be prevented by elevated land in Africa, Spain, Portugal, and Switzerland. For, as the power of the sun increases in the northern hemisphere, and evaporation from the northern seas fills the air more fully with vapour, some of it becomes condensed against these mountains, where local ascending streams in the atmosphere are created, and new horizontal aërial currents are produced, breaking in upon and destroying, for the time, the regular trade wind. The influence of these new movements of the air is seen in the stormy Bay of Biscay and adjacent parts, extending to the British Islands, where it has been observed that northern winds prevail in the winter and spring, when heavy rains fall in Spain. A writer in the *Gardener's*

Chronicle of June 8th, 1844, says—"From information I have received of unusual rains in Andalusia, and along the coast of Algiers, I attribute to them the long continuance of the north-east winds of England and France. When the Duke of Wellington was in Spain in 1809, when his despatches mentioned the bad state of the roads owing to rains, I noticed that we had northerly winds in England; and I have afterwards recorded in my weather journal a current of air towards any place where there has been a great *precipitation of rain or snow.*" I have myself sought for accounts of weather in the southern parts of the Peninsula when we have had continued north winds in England, and those accounts have commonly represented the weather as being extremely wet in Spain when we had north winds in this country, but they are given in such vague language as to be scarcely worth quoting.

The following is, however, a sufficiently intelligible specimen of these accounts. The first is from the *Daily News* of June 6th, 1853, in which it is said—"The weather has been most ungenial in the the south. The *Tagus*, which brought home the Peninsular mails on Friday, experienced very rough weather on her homeward voyage. At Cadiz, the weather was very cold and rough; such weather was scarcely ever remembered there at this season of the year. At Gibraltar, also, the weather was unseasonable; a fleet of merchant-men, mustering between three and four hundred sail, was wind-bound at Gibraltar when the *Tagus* left; the destination of most of them was England. A steam-tug at Gibraltar would be a fortune." And the Lisbon correspondent of the *Morning Chronicle* says, on May 29th, (the same year,)—"This has been the most rainy season ever known in this country, and the crops are all extremely backward." Now, at this time the weather in England was remarkably dry and cold, the wind being generally from the north. The rain that fell at Manchester in February was

only 1·65in.; in March, 1·74; and in April, 2·05; not one-half of their average quantity. The atlas range of the African mountains appears to exercise the same kind of disturbing influence here, when heavy rains fall there, producing new movements of the air, and breaking in upon the more general currents of the atmosphere. These, however, are temporary fluctuations, and are only modifications of the principal winds, as the vapour raised by the sun in the winter and the early part of spring, from the southern portion of the northern Atlantic, is largely condensed amongst the West India islands, and against the Cordillera of the Andes, extending to the equator.

That sagacious and indefatigable observer of nature, Humboldt, has given an account of the rains which precede the rise of the waters in the basin of the Orinoco, and of the winds which flow in the adjoining regions at the time, and the Rev. T. Milner, in his compilation, after quoting largely from Humboldt, says—"The seasons of rains and thunder in the northern equinoctial zone coincide with the passage of the sun through the zenith of the place." "While the breeze from the north-east blows, it prevents the atmosphere from being saturated with moisture." "When the sun, entering the northern signs, rises towards the zenith, the breeze from the north-east softens, and at length ceases; this being the season at which the difference of temperature between the tropics and the contiguous zone is the least. The column of air resting on the equinoctial zone becomes replete with vapour *because it is no longer renewed by the current from the pole.*" Humboldt thus shews why during our summer no regular wind from the north blows over the Caribbean sea. In that season evaporation saturates the air with vapour, not only over that sea, but to a considerable extent over northern parts of the Atlantic, when rains accompanied by local winds and calms alternate about the islands in and near it, the extent of local atmospheric disturbance being proportionate to the amount of vapour condensed in each part at the time.

Towards the latter portion of the winter, however, and particularly about March, condensation generally takes place further north in America, as Cuba, Florida, Louisiana, and Texas are then frequently visited by heavy rains, which in some years extend still further to the north, and produce palpable effects on the winds of the middle Atlantic; making them more decidedly east, and drawing air from the more eastern part of that ocean. These are, indeed, the winds that frequently impede the passage of ships from the United States to England at this season.

In the year 1852, in this country, north-eastern and eastern winds blew almost continuously for two months, that is, from the middle of February to near the end of April, during which time scarcely any rain fell in England. One account in the English newspapers says that "intelligence was received at Lloyds on the 21st April that the wind, which for the last two months had been blowing from the eastward, and locking out the homeward-bound vessels from America, had in the two preceding days shifted to the westward." The newspapers from America up to the 7th of April, also say that at the time these winds were blowing over the Atlantic, furious storms occurred at the Havannah, New Orleans, and Texas, and in parts of the United States further to the north. An arrival from New York up to the 21st April says that "a good deal of damage has been caused by the rising of the waters of the Monongahela and Alleghany rivers, particularly in the neighbourhood of Alleghany city, and at Pittsburg. The waters reached within two and a half feet of the great freshet of 1832." "The papers abound with reports of floods in all the rivers." One account from New York of the 24th says—"Several villages in Virgina had been entirely destroyed by the recent floods." Another that "considerable damage had been done in the neighbourhood of Boston." "The Potomac and Susquehana have also been flooded in an extraordinary way; and on April 19th the great Ohio at Cincinnati was rising."

Now it is evident that these storms and heavy rains must, in the locality in which they took place, have produced important ascending currents in the atmosphere, into which air flowed to feed them, doubtless from the low level of the Atlantic Ocean; and ultimately this air would be drawn from the countries beyond that ocean; and the easterly winds which blew during the two months of March and April in the British Islands may have been, and, we may infer, were produced in this way.* Similar causes are in operation generally in the United States at the same season, though on an average they act with less force and produce less effect than they did in this year. But such operations account for the prevalence of east winds of greater or less strength at this time of the year, in the Northern Atlantic, as well as for the winds of this country then inclining to be more east than north.

But as the sun advances towards the northern tropic, he more fully heats the northern hemisphere, and brings the different parts of it nearer to an equality of temperature. The air of the north, in the lower regions, as stated by Humboldt, then presses with less force towards the south, leaving the atmosphere in the locality without regular winds and comparatively calm; whilst the rise of temperature increases evaporation from the sea and fills the air over it with a greater abundance of vapour. A consequence of this is, that, from causes that are always in operation to produce slight movements of the air, condensation of vapour is begun over some of the elevated lands of Europe, and a south or south-west wind in England may be produced by condensation

* The weather in Lancashire at the period named, in this year, was so extraordinary as to warrant a more particular notice of it. Vapour from the Southern Atlantic had brought large quantities of rain in January and during the first half of February. But after the 17th of February, at the Reservoir, near Manchester, it rained only on 13 days out of 66, and the whole quantity of rain that fell during that time was but .56, or little more than half an inch. This, it will be observed, was when the eastern side of the United States was deluged with rain, and east winds blew in the Atlantic.

in Norway,—a west wind by rain in Germany,—and a north-west by rain or snow in Switzerland; and these different winds may all pass from the Atlantic, taking vapour with them, to the different areas of condensation.

But as condensation now takes place more freely in Europe, and air is thereby drawn from the Atlantic, less vapour will pass from the middle Atlantic towards the West Indies. The Caribbean Sea will now have supplies of vapour only from itself and southern latitudes, and calms will be there experienced until evaporation saturates the air, when local storms will occur, to give place in due time to new summer calms. *The whole northern hemisphere,* at the same time, being nearer to an equality of temperature, and the air over its seas being more fully saturated with vapour, a number of comparatively small areas of condensation in the north will be created, towards each of which winds will blow with a force proportioned to the amount and rapidity of the condensation which takes place in each. Under these circumstances, it is evident, that no general wind can blow from this country towards the south-west, as it does during the month of March.

On the arrival of June, an approach to the state of the atmosphere that has been described is experienced, in the British Islands, and, in July and August, the air over them and the adjacent seas becomes pretty fully charged with vapour. The dew-point approaches the temperature when, on any moderate movement taking place which shall cause the air near the surface to be raised to a considerable height in the atmosphere, condensation commences and a summer storm is produced. An ascending current then carries the vapour that has accumulated in the lower part of the atmosphere into lofty and cold regions, condensation is rapid and energetic, and heavy rain falls, producing a local storm. But as the vapour will have been furnished from the immediate locality only, and a fresh continuous supply cannot be obtained from a distance, because similar operations are going on there,

the storm soon ceases, as a storm in harvest generally does; and the result is, that the atmosphere in the part which had been previously saturated with vapour, is now left comparatively dry, and the air is said "to be cleared."

But condensation, we have seen, takes place more frequently against the sides of mountains than in the open atmospheric space. The saturated air, forced up the inclined plane of a mountain, has some of its vapour condensed there, when fresh air presses into the vacuum that is formed, and thus a supply is furnished to the locality which may be brought from greater or less distances, according as this particular part, or rather the condensation that is going on in it, is able to draw supplies to itself. The pennine chain of mountains which separates Yorkshire from Lancashire thus receives a large quantity of rain in the summer and autumn,—the mountains of Cumberland receive a still larger supply,—and the western parts of Scotland have their full share, the principal part being brought from the south-west or west, as the warmer sea that furnishes the vapour is situated in these directions; and this accounts for the south-west and west winds that are so prevalent in these parts in the summer and autumn. The Continent of Europe also has a number of elevated lands against which condensation takes place freely, and the supply of vapour for these parts must also, directly or indirectly, come from the Atlantic Ocean. Hence the westerly winds that blow far into the Continent, are constituted of masses of air drawn from the space over that ocean, many of them passing over, or near to, the British Islands, after having traversed the sea, sometimes from so remote a distance as the United States of America and the West Indies.*

* In the *Literary Gazette* of February 12th, 1853, it is stated that Col. Sabine, in a paper read to the Royal Society, said that "recent investigations have led to the inference that opposite conditions of weather prevail simultaneously in the same parallels of latitude, under different meridians, and that in particular, Europe and America usually present such an opposition, so that a severe winter

When treating on disturbance in different parts of the atmosphere, we are not able to speak of the place in which it occurs with the same precision that we can when describing what takes place on the surface of land. The exact situation of a mountain, a lake, or a river may be given, but an ascending atmospheric current, or the horizontal wind that blows towards it, can only be pointed out in a general way. Different atmospheric movements, too, often originate in different places at *the same, or nearly the same time*, and they act with such irregular forces, and affect each other in such different directions, as to render it impossible to define their respective limits, or to measure the degree of power with which each acts on the adjoining portions of the atmospheric mass. They also cross each other in various ways, whilst each separate movement may be propagated through the whole mass in all conceivable ways, and to undefinable distances. Condensation may be taking place in Spain, in Switzerland, and in Norway at the same time, and the ascending currents produced in these different parts of the world are supplied from other parts according as the adjoining air presses with less or more force towards each vacuum:—and it may be either in direct lines, or by circuitous routes that they pass, whilst fresh areas of condensation may be created by these new currents passing

here corresponds to a mild one there, and *vice versâ;* and recent theories of the distribution of heat on the surface of the globe profess to furnish the explanation." But this transfer of the severe winter in the same parallel, from one part to another, in different years, is not confined to longitudes, as the same thing may take place in latitudes. And it is very likely that the causes which determine the weather to be wet or dry, in a particular part, on St. Swithin's day, (July 15,) may change their places in different years, and cause wet or dry weather, according as the one or the other prevails on that day, to continue for a considerable time. If condensation take place on that day sufficient to produce rain, vapour from the Atlantic may be brought thence freely for some time;—but if the vapour should at that period be taken to some other part, say America, it may continue to go towards America for some time. The supposed influence of St. Swithin must, we presume, have appeared to our forefathers to be in accordance with the weather experienced at the time in each year.

over other elevated lands,—producing various and indefinite changes, and rendering it impossible to define the limits of particular movements, or to measure their forces. All that is possible, therefore, in the present state of our knowledge of the subject, is, to seize the most prominent facts, and ascertain, as far as we are able, the nature of the causes that are in operation, leaving to future inquirers the task of making more minute investigations as knowledge is extended.

All this being considered, and due allowance being made for the obscurity of the subject, we may then say that it has been shown by reasonable evidence, that the north-east and east winds of March in this part of the world are caused by condensation of vapour in or about the West Indian Islands, and the United States of America drawing air from this locality to fill up the partial vacuum that had been there created by that condensation;—and that the various and irregular western winds that blow over the Atlantic in the summer and autumn, are caused by vacua produced by condensation over the elevated lands that exist in the British Islands, and on the Continent of Europe: and that these last-named winds sometimes continue through the early part of the winter, while the Atlantic Ocean retains some of its summer warmth, giving us the heavy rains that occasionally fall at that period of the year.

ESSAY XIV.

On Winter Isothermal Lines in the Northern Hemisphere.

To attempt to exhibit isothermal lines in the atmosphere, *on a map of our globe*, was an important step in the progress of meterological inquiry. It was previously understood that those lines did not coincide with lines of latitude, and that they were differently affected by the surfaces of the globe being dry or covered with water: but the great inequality in their distances from the equator was not fully known until the construction of a Map of Isothermals by Humboldt exhibited them.

The earlier attempts made were to show the lines of equal mean annual temperature; this, however, it was soon perceived, indicated very imperfectly the causes of the irregularities, as those causes evidently operated in both the northern and southern hemispheres differently in the winter to what they did in the summer. And it was felt to be particularly desirable that we should know what are the influences which determine the isothermal lines to be so irregular, in the winter of the northern hemisphere. This want has recently, to a considerable extent, been supplied by Professor Dove, who has, with great labour, constructed Charts showing the monthly isothermals at various distances from the equator, in both the southern and northern hemispheres. We are thus furnished with additional means of tracing out the causes that are in operation to produce the diversified temperatures which are found at the same times over the same latitudes on different meridians.

The general mean temperature of the air, over the entire globe, near the surface, is by the Professor taken at 58°.2 of Fahrenheit,—the mean of the southern hemisphere being 56°.4, and of the northern, 60°. Thus there is a certain deviation, in each hemisphere, from the mean temperature of the whole globe. But the departures from the means in certain parts of various latitudes, are far greater than that which takes place in the two hemispheres, and are such as to show that some powerful cause is in action to produce the results that are found in many localities.

In addition to the effects produced directly by the sun, the influences pointed out by Professor Dove, as producing various results, are,—*the irregular distribution of land and water,—the different effects of the sun's rays on those substances, and* the influence of warm or cold currents of water of the ocean on the temperature of the part.

There is no reason to doubt that these influences do produce certain effects on local temperature, as we know that the direct rays of the sun act variously on different substances, producing in them different temperatures, which to some extent must affect the air in the localities where they exist. But it is not enough to show that these causes produce some effect, as we require to be satisfied that they produce the effect attributed to them. And if they were the real causes, it could be shown that wherever they are in full operation, similar effects are produced.

In the winter of the northern hemisphere, when North America and Europe are cooled down, as shown in the isothermals for the month of January, the temperature is comparatively high over the sea in that part of the Atlantic that is between these continents. But does this difference correspond with the relative extents of land and water in such way as to indicate that they have the relation to each other of cause and effect? The Northern Pacific Ocean is about twice as broad as the Northern Atlantic up to the latitude of above

50°—but the former is not proportionately warmer than the latter. It is on the contrary colder, as may be seen from the isothermal lines over the two oceans and adjoining parts—the temperature that is found at 58° of latitude in the Pacific being carried as high as about 70° in the Atlantic and Polar Seas, as may be seen in the Chart, plate 5. These facts indicate that relative breadth of land and water is not the cause of the irregular rise of the isothermal lines in these parts; and they show further that even in winter, when the land is generally much colder than the water, the temperature may, by some cause, be made as high over the land as over the sea.

If the water of the ocean produced the effect that has been ascribed to it, the isothermal lines would be at the same height, in the same latitudes, over the land on each side of the same ocean, but it is well known that they are not. The isothermals, as may be seen in the Chart, rise in the winter from central Asia and Siberia to the middle of the Pacific Ocean, showing that the air over the water is there warmer than the air over the land, but they rise still higher as they approach the American coast, and attain the greatest height in that part which is near to, or actually over, the land in America, thus exhibiting the air over the land there as much warmer than it is in Asia, and even warmer than it is over the water in the middle of the Pacific in the same latitude. In the Atlantic, too, the same isothermal that on the American side of that ocean is in the latitude of from 42° to 44°, near Newfoundland, reaches to more than 70° on the European side. And Newfoundland, though close to the warm gulf stream, *is colder than Iceland, which is surrounded by a far colder sea*, and touches 66° of latitude.

Professor Dove speaks generally of the gulf stream of the Northern Atlantic, as materially affecting the temperature of the part up to a high latitude, but he does not show it to be the cause of the phenomenon under consideration. It is well

known that that stream is turned from its northern direction off Newfoundland, across the Atlantic to Ireland and the Bay of Biscay, and it is even thrown back on the coast of Africa. Humboldt thus speaks of it in its northern part. He says—"In the meridian of Halifax, the current is nearly 276 miles broad. Here it turns to the east, its western margin touching the extremity of the great bank of Newfoundland. From this to the Azores it continues to flow to the east and south-east, still retaining part of the impulse." "From the Azores it directs itself towards the straits of Gibraltar, the island of Madeira, and the coast of Africa." This account is quite at variance with the idea that the gulf stream ascends to a great height in the Northern Atlantic. The frequent appearance of icebergs off Newfoundland indicates that a current sets in here, not northward, but towards the south. And Milner says that "the north polar current appears to strike the coast of Asia, and, passing round the north cape of Europe, it crosses the upper part of the Atlantic, running to the south-west."* Malte Brun also says that "the polar currents of the north exhibit very remarkable effects. These currents are particularly observed in the northern frozen ocean, on the coasts of Greenland, of Iceland, and Lapland. They have usually a direction from north to south, occasionally the reverse. They bring upon the coasts of Iceland such an enormous quantity of ice that all the northern gulfs of the country are filled with it to the very bottom, though they are often 500 feet in depth." And Lizars says, in his *Geography*, that "the influence of the polar current is felt all along the shores of Britain, from the Orkneys southward. Entering the North Sea it has no other outlet but the Straits of Dover." From these extracts it seems that the assumption that the warm gulf stream flows into a high latitude in this part and warms it, is not only unwarranted, but directly at variance with known facts.

* Milner, p. 360.

But if neither the proportional extent of the surface of the sea, as compared with that of the land,—nor the flow of a warm current of water carries high temperature to these northern latitudes, what is the cause of such temperatures being found there? The answer to this question has been substantially given where I have pointed out the cause of all the great local heatings of the atmosphere, and of the winds that prevail over the surface of the globe. But a reply is virtually prepared by Professor Dove himself, where in his remarks he says—"This surface (of the globe) being a highly varied one, the sun's influence on it is also constantly varying, for the impinging solar heat is employed in raising the temperature of substances which do not change their condition of aggregation; but when engaged in causing the melting of ice, or the evaporation of water, it becomes latent. When, therefore, the sun, returning from its northern declination, enters the southern signs, the increasing proportion of liquid surface upon which it shines causes a corresponding part of its heat to become latent, and hence arises the great periodical variation in the temperature of the globe which has been noticed above,"—meaning the difference of temperature of the northern and southern hemispheres. But why should we suppose that this effect of evaporation of water is found only in the relative temperatures of the two hemispheres? And why not trace the effects of condensation of the vapour, as well as of the evaporation of water? It is no doubt true that heat is absorbed and made latent wherever vapour is produced,—but it is equally clear that that heat is given out and made active wherever the vapour is condensed. That part of the North Pacific Ocean which is within and near to the northern tropic, evidently supplies a large amount of vapour to the atmosphere, and the latent heat which it contains is given out and warms the locality where it is condensed. Much of it is, in fact, taken across the Northern Pacific to the western coast of America, and is condensed in the neigh-

bourhood of the Rocky Mountains, liberating the heat that it contained, and warming the part. And it is to this process of condensation of atmospheric vapour, and not to the contiguity of the Pacific Ocean, that we have to attribute the winter isothermals being higher over the American coast than in eastern Siberia or over the middle of the Pacific Ocean.

The vapour which passes over the Northern Atlantic, and which is condensed about the British Islands and Norway, is supplied from the tropical and other seas north of the equator. The seas near to the West Indies constitute the most southern point of departure of this vapour, and in the month of January it is known to be carried by south-western winds to those localities where the isothermal lines advance farthest towards the North Pole. It is accordingly to the condensation of this vapour, and not to the neighbourhood of the Atlantic Ocean, that we are to attribute the high temperature of this part of the world in the winter. The Atlantic Ocean is as near to Labrador as to Norway, but there is little condensation of vapour on the coast of the former, whilst there is much about the latter,—the former is consequently cold compared with the latter. Indeed, as far as we know, condensation of vapour is the only influence that operates exclusively on the eastern coasts of the two oceans, the Northern Pacific and the Northern Atlantic; to it, therefore, we may attribute the warming of the locality in the Arctic Ocean, near Spitzbergen, as indicated by the isothermal lines. The process of condensation furnishes a constant and abundant supply of heat,—a process not like that of diffusion through contact, nor resembling the feeble effects of radiation from surfaces of water not very different in temperature; but one that consists in the energetic chemical action which converts an aëriform substance into a liquid, and which consequently changes the heat contained in the aëriform substance from a latent to an active state of existence. The greatest irregular rise in the isothermal lines is found in the winter of the

northern hemisphere, just at the time when the condensation of vapour produces most effect on the temperature of the air. And the temperature rises the most above the mean of the *latitude along that stripe where the largest amount of condensation takes place*, and there the high temperature reaches the highest latitude.

Professor Dove speaks of this locality in the following terms. He says—"In Scandinavia the circumstances are still more extraordinary: from the intervention of the British Islands the southern parts of Norway are less open to the warm sea current than the northern parts, and hence in January the temperature actually becomes warmer in proceeding from south to north, and at the North Cape the south-east winds are the coldest. Both the Scandinavian Alps and the Rocky Mountains in America form dividing walls in respect to climate." It will be observed that the Professor does not attempt to trace the effects of condensation of vapour in these parts, to the formation of which he had attributed important results, in taking up heat and making it latent in the southern hemisphere, and he is therefore obliged to suppose that the effects under consideration are produced by warm sea currents, though others represent those currents as coming from the north. As to the south-east winds at the North Cape being the coldest, that is doubtless caused by their being land winds which had not been warmed by condensation of vapour, as the south-west winds are.

Dillon, in his *Winter in Iceland*, speaks of "the awful gales that never cease to blow there," and of the very heavy snows that fall. He says that "in the course of an hour the whole front of the house, windows, doors, and all were snowed up to the roof."* And the same kind of weather, particularly the snow-falls, is found in Norway, Lapland, Spitzbergen, and Nova Zembla.

I have elsewhere shown that when vapour is converted into snow, there are two warming processes gone through,—first,

* Dillon, p. 167.

condensation of the vapour and production of liquid particles, and afterwards congelation of the liquid particles and formation of ice; and each of these changes liberates much heat and raises the temperature of the part. The wind that carries vapour into the arctic regions must, no doubt, produce a certain effect on the surface of the water over which it passes, and must tend to put it in motion, to a greater or smaller extent, towards the north. But any oceanic current that may be thereby produced must be considered as being independent of the gulf stream. If the south-west wind in high latitudes forces water from the south to the north, even to a small extent, this water will be thereby rendered somewhat warm for the latitude in the whole of its course, but this water would be no more able to raise the temperature of the locality to the height that it attains, than is the still warmer water of the gulf stream able to raise the temperature of the air over Newfoundland, where it merely produces a cloud near the surface.

The cause that really raises the temperature on the western coasts of America and Europe, increases that of localities which are distant from the sea, and consequently far removed from its influence. This is shown in many inland parts which are made warmer by condensation of vapour. It is exhibited in a striking manner on the south-western side of the lofty Himalaya Mountains that are at a great distance from the sea. The warming influence of condensation, at great heights in this range, is such as to affect vegetation to a material extent, and grain is found there to ripen at elevations which, but for the operation of this cause, would be subjected to continued frost. The great height at which this takes place, prevents a simple comparison from being made between this and other parts that are at a lower level, but there seems to be no reason to doubt that it is condensation of vapour that warms the Himalayas to great heights.

Over nearly the whole surface of the globe, the land as well

as the sea, the solar heat is largely expended in vaporising water. From the surface of the sea in all latitudes evaporation takes place according to the temperature of the water and the dryness of the air: but as the temperature of the sea seldom rises above 80°, evaporation over the sea is seldom very energetic in warm climates. Land is however often raised to a much higher temperature, and evaporation from it, as long as any moisture remains, takes place with proportionately greater energy, and it extends to some depth below the surface. And this process, we know, regularly takes up, not only water, but a large amount of heat, both from sea and land, and keeps it in a latent state, as long as the vapour remains an aëriform substance. The aqueous vapour of the atmosphere is indeed a capacious storehouse of heat,—which heat, from the operation of certain causes already explained, is liberated in some localities in greater abundance than in others; and over the whole globe, wherever the temperature is raised both by day and by night much above the mean for the latitude, the rise may be presumed to be caused in a far greater degree by condensation of vapour, followed sometimes by congelation, than by the breadth of surface of adjoining seas, or by particular oceanic currents. In cold latitudes in the winter season, over land, where little or no vapour is condensed, the part is always cold, but where condensation takes place freely the temperature is raised: and whenever the stream of vapour flows into high latitudes to be there first condensed and then frozen, the isothermal lines rise with it, as they do up to Spitzbergen and Nova Zembla.

In order to complete the formation of his lines, Professor Dove was obliged to examine and compare long series of observations, made at points more or less distant from each other, with others that had been made less frequently in intermediate parts. And he says it "appeared that important variations are never merely local, but that the same character of weather prevails over large portions of the globe;—that

the anomaly reaches its maximum in one spot,—in receding from which it lessens more and more, until, passing through places where the thermic conditions are in their normal state, an opposite extreme is reached, which so compensates the first, that the general sum of warmth distributed over the earth at any particular time of year is the same in different years, although the values which make up the sum may be very different. Knowing the prevailing character of the weather in particular places, in the different years, we are enabled to deduce from the deviations at a few normal stations, where the observations extend over a long series of years, the quantitative corrections to be applied to the results of observations continued for only a few years."

From this statement, as well as from abundant evidence, we are authorised to infer that the immediate operating cause which determines irregular changes of temperature in certain parts, must be moveable in its action, though derived from a source that is unchanging and uniform: and this is the character of atmospheric heating by condensation of vapour. Evaporation of water, in each year, being from the same extent of sea and land, must be nearly uniform in its energy,—and must produce about an equal amount of vapour in each year;—but from the working of those innumerable disturbing causes, some of which have been adverted to, which influence the distribution of the vapour by winds, a larger proportion of it may be taken to one part in one year, and to another part in another year, but each part, at the time that it has the most vapour condensed within it, will be the most heated. In one winter, from causes which we are unable to trace in detail, the vapour may be taken to America to more than an average extent, and the British Islands may be left comparatively dry and cold. In another, the winter winds may be different, and may bring more vapour and warmth to the British Islands.

But where adequate causes exist to determine the vapour to flow to particular localities every year, as they do near to

Spitzbergen; to be there condensed in far greater abundance than in other parts in the same latitude, the temperature of those localities will be proportionately raised. The power which vapour has of conveying heat irregularly to places in different years, equally enables it to take the heat regularly from a warm to a cold latitude,—and *to one part of a cold latitude instead of another.* And the influences which deter*mine vapour to flow from the comparatively* warm parts of the Atlantic to the Arctic Ocean near Spitzbergen, to be there condensed and frozen, are the real causes of the great rise of the winter isothermal lines in that part, vapour being the agent through which this result is produced.

Recently, at a meeting of the British Association, eminent men have spoken of the gulf stream of the Northern Atlantic being the cause of the lines of high temperature extending so far north in the winter about the British Islands, apparently without having themselves taken pains to examine the subject, and without showing that the gulf stream does flow far north. But while Newfoundland can be pointed at as possessing a very cold winter climate, though it is close to a warm part of the gulf stream, and whilst the western coast of North America and Cape Horn can be shown to have warm climates for their latitudes in the winter, without any warm oceanic current, similar to the gulf stream, flowing upon them to produce the climates, such general assertions cannot be admitted to have any force. If indeed isothermal lines in the water of the ocean about the British Islands and Norway could be shown to have irregularities corresponding with those of the atmosphere in those parts, there would be some evidence of the temperature of the water determining that of the air; but at present the existence of the moderately warm water of the Atlantic Ocean, and the high temperature of the atmosphere over the northern part of that ocean, appear to be merely coincident circumstances, without having the relation to each other of cause and effect.

ESSAY XV.

On the Separate Pressures of the Aqueous and the Gaseous Atmospheres.

The general gaseous atmosphere, when at rest, has an equilibrium of pressure at the surface of the sea: it would therefore be the same in all parts of the world, if the temperature were everywhere the same at the same level. And those changes of temperature, in the mass of the atmosphere, which are produced directly by solar rays, are so gradual and slow as to enable such a highly elastic body as the atmosphere readily to re-establish the equilibrium after it had been disturbed by direct solar heat. The gaseous pressure, therefore, would be about the same over every part of the globe at the level of the sea, were there not some other disturbing cause that operates *locally;* and that there is such a cause, is sufficiently indicated by the local and temporary changes of the barometer that take place in various parts. Attempts have been made, not entirely without success, to trace iso-barometric lines over the globe, and if we had them in considerable numbers that could be relied upon, they might materially assist in our inquiries.

With reference to this subject Kaemtz says—"We may admit that—

	mm.
At the sea-coast the general mean pressure is	761.35 *
At the equator it is only about..................	758
At the latitude of 10° the pressure increases, and between 30° and 40° of latitude it attains its maximum........................	762 or 764 = 763
Starting from this zone, it diminishes to......	760
And more north, it descends to about.........	756."†

762 millimetres are equal to 30 inches of mercury.

† See Plate 5.

This imperfect statement of atmospheric pressure in different latitudes is made up of averages. It presents a range of nearly a quarter of an inch of mercury; and Kaemtz appears to think that the amount of pressure has some dependence on mere latitude. In speaking, in the same part of his book, of the total pressure as ascertained by the barometer, he does not, however, deem it necessary to distinguish the aqueous portion from the gaseous.

But there are parts of the world where the average difference of pressure is more considerable than any of those just given. In Schouw's table Tripoli is put down as having a mean of $767.41^{mm.}$, whilst Reikiavig, in Iceland, has one of only $752^{mm.}$, which makes a difference between these two places of more than half an inch of mercury.* This difference is, however, much exceeded by places in the southern hemisphere. Captain Foster found that the average pressure near Cape Horn, for a considerable period, was only about $29.2^{in.}$, whilst at Valparaiso it is $30.1^{in.}$, and at the Cape of Good Hope, $30.2^{in.}$ Captain Ross also found that in the parts of the antarctic seas which he visited, the pressure was very low, even less than about Cape Horn. Now, in these localities, the respective pressures found, though so unequal, are general averages, and we have to endeavour to ascertain what can cause such long-continued unequal pressures, in a body like the atmosphere, which tends so strongly to establish an equilibrium.

In doing this, it will be necessary to bear in mind the causes that are presumed to be in operation to produce the results, namely, varying quantities of aqueous matter in the atmosphere, and local alterations of gaseous temperature; and these causes are considered sufficiently powerful to produce *all* the effects exhibited in the different latitudes; taking the parts about the equator first, with a dew-point of 80°, indicating, according to common assumption, a quantity of vapour in the atmospheric column equal to an inch of mercury, which would leave 29 inches of gaseous pressure to make up the

* See figures on the Chart, Plate 5.

total, supposed to be 30 inches. But with the high gaseous pressure which is admitted to exist on each side of this part of the globe, and with such winds blowing towards it as the north and south-eastern trade winds, how can we imagine, on the theory generally recognised, that gaseous pressure can be so low in this locality as is thus represented,—only 29 inches? Direct solar heating of the mass of the atmosphere, as has been shown, is never considerable, it being confined mostly to the portion near the surface; and that heating would tend to heap up the gases within the tropics to enable them to flow over north and south towards the polar regions; it is, therefore, difficult even to conceive that the direct influence of the sun could make the gaseous pressure here so small, as it must be if an inch of mercury is to be allowed for vapour pressure.

For reasons already given, however, the real quantity of aqueous matter in the part, in the two forms of vapour and globules of water, cannot be considered to be much less than that named, that is, a quantity equal in weight to an inch of mercury. Because, although there is certainly much less vapour generally in the upper part of the atmosphere than has been supposed, there is here much water floating in it, as is seen in the thick stratum of mist that constantly fills the air in the part.* But this mist being regularly formed by successive condensations of vapour, and the vapour being as regularly carried up in an ascending current that attains a great height, is constantly heating and expanding the gases. Condensation, therefore, may be confidently presumed to heat, expand, and lighten the gases to so great an extent as to make their pressure, even when added to that of the aqueous matter that is present, less than the mean, and not more than it is actually found at or near to the equator.

* Perouse says—"A few days after our departure from Teneriffe we left those serene skies only found in the temperate zone; instead of which a dull whiteness, between fog and cloud, always prevailed. The horizon was contracted within less than three leagues, but after sunset the vapour was dissipated and the nights were constantly fine."—P. 19

The parts over the Atlantic Ocean, distant say about 30° of latitude from the equator on each side, where the barometer stands the highest, are occupied to a considerable extent by the north and south-eastern trade winds, which, in these parts, have but little condensation of vapour going on in them, and the great mass of the air in these winds will consequently not be heated by condensation. We may therefore conclude that the cool state of the gases in these latitudes renders them heavy, and produces the superior average atmospheric pressure that is found in them.

As we proceed farther from the equator, the general temperature is lower and the tension of vapour is less; the former tends to increase and the latter to decrease the total pressure; and, where the atmosphere is undisturbed by condensation, the two causes would appear to produce nearly a mean atmospheric pressure. This is seen principally in the northern parts of America and Asia, where there is but little vapour, and that little is not much disturbed by condensation. In Iceland, however, where there is much condensation, the pressure, as we have seen, is low. The same general facts are traceable in this country and on the coast of Norway, all those places showing effects of condensation.

In the southern hemisphere there are features not observable in the northern, resulting apparently from the different proportions of land and water surfaces, in the two parts. In the northern, the great extent of land leaves but a comparatively small extent of water from which evaporation takes place, hence the atmosphere is there comparatively dry and clear, and the dew-point generally low compared with the temperature. But the southern hemisphere, beyond the latitude of say 50°, is almost wholly sea. Evaporation consequently takes place from a large surface of water, and much vapour is sent into the atmosphere, making the dew-point high for the temperature. The air is consequently generally filled with mist, in this respect resembling the hazy tropical regions; and the

extensive condensation of vapour warms the air in the middle and upper parts of the atmosphere, and makes the whole mass of air swell and expand, leaving it lighter than in the other hemisphere.

The solar rays which, on the broad extent of land of the northern hemisphere, heat the land to a high temperature, are in the south united with water, and pass in vapour into the atmosphere. The quantity of aqueous matter in the air in the south must therefore be large, whilst the total atmospheric pressure is found to be small; the gaseous pressure must consequently be small. This state of the southern atmosphere, however, seems consequent on—not the large proportional surface of water alone, but also on the few elevations that exist there to bring on local condensation. Spread over Europe and the western part of North America, extending into the polar regions, there is a large number of mountains up which winds carry vapour, where it is extensively condensed, and these elevated localities become atmospheric vortices, into which more vapour is borne by the winds from great distances, to be there condensed. The northern atmosphere is thus relieved from a considerable part of its vapour, as it always is, by extensive condensation. It is well known, for instance, that a thunder storm clears the air of vapour. In summer, when evaporation is active, the air in a short time is charged nearly up to the point of saturation, when, from some cause which we need not trace, a thunder storm occurs. The vapour is first carried sufficiently high to commence condensation, and a local ascending current is created, into which adjoining air and vapour rush from considerable distances, and are carried to higher regions, to have the vapour condensed to a large extent by the cold due to the elevation: the result is a heavy fall of rain. The vapour that went up as an aëriform substance comes down as a liquid, leaving the atmosphere dry and clear. In just the same way many mountains condense the vapour of the northern hemisphere, leaving the air there

comparatively free from it, and ready to acquire the cool temperature which belongs to dry air in the middle and upper regions of northern latitudes. In the southern hemisphere, particularly beyond 50° of latitude, there are few elevations of land to collect and condense the vapour that is constantly furnished from the immense surface of the Southern Ocean; it is therefore slowly, but extensively, condensed in the open atmosphere, and to a certain extent warms and swells it, leaving the whole atmosphere less heavy than in the north.

But though there are only few elevations in the south, as compared with the north, there are some, and they show the effects of the peculiar state of the atmosphere in this hemisphere. The few elevations that exist there are remarkable for having an abundance of rain, and for the strength and continuance of the winds that blow about them. These striking features are seen in Kerguelen's Land,—Van Diemen's Land,—New Zealand,—Auckland and Campbell's Islands, and generally about such elevated land as exists in the colder latitudes of the hemisphere. But distinguished among them may be particularly noticed the extreme point of South America about Cape Horn. Up the high lands of this part of the world, the saturated air of the southern hemisphere rushes with a force and constancy not to be paralleled in any other part. Deluges of rain are almost continuous, and the vortices created by them cause the saturated air to press towards them from a large portion of the Southern Ocean, reaching almost to New Zealand on the west, and far to the south, as is shown by the general direction of the wind in those parts. This abundance of condensation of vapour must heat the air in the vicinity of Cape Horn up to a considerable elevation, and render a thick stratum of it light, thus accounting for the very low barometer observed there by Captain Foster. The neighbourhood of Victoria Land, as ascertained by Captain Ross, presents the same general features as Cape Horn, allowing for the greater proximity of the former to the pole. The general gloom of the

sky in this part,—the frequent falls of rain and snow, and the low barometer,—all indicate the presence of an atmosphere highly charged with vapour in proportion to the temperature at the surface, which atmosphere, we presume, must be drawn from warmer latitudes towards the part by condensation. There being then an abundance of aqueous matter in the air to furnish its full proportion of weight, the low barometric pressure that is found in these localities is evidently caused by the warming and lightening of the gases, but the aqueous matter is not all in the form of vapour. The particles of water that cause the thick and gloomy mist have their proportion of the weight, though it may be sustained by the gases in which they float,—that weight, however, must be counteracted by the lightening of the gases themselves, to produce the low aggregate pressure that is shown by the barometer to exist there.

From such evidence as can be obtained on the subject, we thus arrive at the conclusion, that in every part of the world, where there is a high average barometer, it is due to the gases in the part, up to a considerable height, having fully acquired the low temperature due to their elevation,—as then a greater weight of air exists in the same space than when the gases are locally warmed;—whilst, where the barometer is low, it is always a consequence of heat having been conveyed by vapour to warm the gases. This view also enables us to account for the puzzling fact so long observed, of a moist atmosphere being accompanied by a low, and a dry one by a high barometer; which, as the material that constituted that moisture adds to the weight of dry air, seemed very surprising and even contradictory. It also authorises us to correct an error that is to be found in most of our meteorological works, namely, that moist, is lighter than dry air. There can be no doubt, that, considered independently of temperature, any vapour passed into dry air adds to the total weight of the mixture as measured by the barometer. The whole of the

gases on the globe have a certain weight, be it more or less, and all the aqueous matter that is diffused through them has also a certain weight; and when we speak of, or compute, the total weight of the atmosphere, we have to add the latter to the former. Temperature being the same, to say that moist air is lighter than dry air, is to say that the whole is less than a part. It is true that the specific gravity of aqueous vapour, considered separately, is less than that of the atmospheric gases, but when mixed with them the vapour adds as much weight to the gases as it possesses. The vapour penetrates into, and exists within the gases, just as much as the gases exist in the vapour, each having its separate weight; and when both are in a state of rest, each presses separately and independently on the surface of the earth, and against the mercury of a barometer which may be placed on that surface.

Some meteorologists, indeed, from their language, seem to think that when vapour first penetrates the gases, they are swelled by it, and thus become permanently lighter, and this idea is countenanced by the temporary effect that is produced when vapour first enters the gases. Vapour, discharged suddenly against a mass of the gases, impinges on them, and when it penetrates them and is pressing further through them, it no doubt tends to force them forward or upward, as the case may be. This is shown by steam being used to blow out air from a vessel that contains it, but this is no more than what one gas will do with another. Nitrogen will act thus on oxygen, and oxygen on nitrogen; but when these gases have fully penetrated each other, and each rests on the earth, each exists independently of the other, and is in the state that it would be if it were in the atmospheric space alone; and so it is with the atmospheric vapour and the gases. It may, and we have presumed that it does, at first and temporarily act against the gases. It has, indeed, been shown that the actual tension of the vapour which is ordinarily found in the middle of the day near the surface of the earth, is partly due to this

cause, the gases temporarily obstructing its expansion into the atmospheric space. But when the vapour has fully diffused itself through the gases, and rests independently on the earth, it exists within them without affecting them. This is a consequence of the law, discovered by Dalton, of mechanical diffusion of aëriform substances through each other, and of their independence of each other when so diffused.

Globules of water, on the contrary, when floating in the gases, rest upon them, because those globules are not aëriform, but liquid, and the gases sustain them for the time because they interpose an obstruction to their descent, just as they would to the descent of any other light substance. But the vapour being an aëriform body, presses with a weight of its own on the surface, and although for the reasons given we cannot admit the tension of vapour to be always a correct measure of its own weight, yet there is no doubt that it has a certain amount of pressure, and that amount is so much to be added to the pressure of the gases,—sustaining, as they often do, at the same time, the weight of the particles of water that may be floating in them.

There is, then, no reason to doubt, that the greater changes of total average atmospheric pressure, as measured by the barometer, which take place in different parts of the world, are due to the same causes as have been traced in the smaller ones. But we know that such very great and sudden reductions of pressure sometimes occur, as to cause the barometer, in a short time, to fall as much as two or even three inches; and through the extreme mobility of the materials that are in action, great difficulty has been experienced in explaining, or even in conceiving, what can be the cause of such great and rapid falls. The difficulty, indeed, is so great as to oblige us to have recourse to analogy, and to apply the knowledge which we have obtained of the nature of the smaller and the average changes, to the larger and sudden ones;—presuming, that when certain causes, operating with a given degree of

energy, produce a certain amount of effect, the same causes, when operating with greater energy, will produce a proportionately greater effect. Having seen that lightening the gases, by the warming process of condensation of vapour existing within the mass of the atmosphere, was the cause of the fall of the barometer when the changes were small and regular, as well as when considerable averages were taken, we may reasonably presume that the same cause is in operation in great, irregular, and sudden changes. Let us then endeavour, from a general view of the subject, to conceive what may be the circumstances that lead to one of those great falls of the barometer which sometimes take place.

Say that, in a certain locality the atmosphere to a considerable height is charged with as much vapour as it can hold in an uncondensed form, and that in the outer portion of it, or in adjoining parts, dissolving clouds exist which by their evaporation cool the gases intermixed with them, and cause these gases to descend. The uncooled saturated air being then a little warmer and lighter than the cooled air, the former will be pressed upwards by the latter, and some of the vapour in the ascending column will be condensed. The whole of the column will now be warmed and expanded by the condensation that takes place within itself, and the heavier adjoining air will press and follow it up with greater velocity, the process increasing in energy and rapidity as condensation proceeds, until the whole ascending column, up to a great height in the atmosphere, is heated and made very light. Under these circumstances the pressure of the warmed column on the surface must be materially reduced, and a barometer placed under the column would, by its fall, show the extent of the reduction. But notwithstanding this reduction of total pressure, the quantity of aqueous vapour in the column must, under the circumstances described, be increased, the warmed ascending current permitting more of it to remain uncondensed in the higher part than would have been possible at that height with

the previous lower temperature: whilst the cloud which is always formed at such times in the outer part of the column would load the gases there with additional globules of water, together making the aqueous part of the atmosphere heavier. The heating and expanding of the gases must, therefore, be sufficiently great to counteract the increased weight of the aqueous matter, and, at the same time, greatly to reduce their own weight. And to some such heating as that just described we have to attribute the great falls of the barometer, approaching three inches of mercury, that sometimes occur; and when such a change takes place in a whole column, it is obvious that the heavy adjoining air will rush as a wind towards the comparative vacuum that exists; but this rush, be it observed, does not occur until after the vacuum has been formed:—the fall of the barometer may therefore precede the rush of wind, or give warning of the coming storm.

This will also account for the fact, that the barometer sometimes begins to rise during the storm. The heating and expanding of the air take place as soon as the first vapour is condensed, and when only incipient cloud, not sufficiently dense to be seen, is forming. And when the same process is going on all around the observer, to a considerable distance, as is common under such circumstances, it may be some time before sufficient cloud is produced to become palpable to the view; for the cumulous cloud, when forming, like a gas jet in burning, makes for itself an envelope, but to see this envelope it is necessary to be outside of it, and looking at it in profile. To those beneath, it appears at first to be only a slight mist, which afterwards darkens as condensation increases, until at last a black thunder cloud may be formed. But the condensation of vapour may then possibly have diminished, and the rushing in of cool air may have partially restored the equilibrium of pressure, and the barometer may have begun to rise though the storm may still be raging. We may conclude, then, that rapid expansion of the column of air by heat of

condensation, up to a considerable height in the atmosphere, is the cause of the great and sudden falls of the barometer that sometimes occur; and those falls are likely to be the greatest where the heating begins in the lowest, and consequently the densest parts of cold regions, and ascends the highest in those regions. The low heavy air of such parts is greatly expanded by the heat of condensing vapour, and being near the surface, the diminution of pressure that follows, affects only a small area of that surface, within which however the diminution is great. But as we proceed to warmer climates, though the quantity of vapour is there much greater, yet, as condensation commences at a superior elevation, a higher and rarer portion only of the atmospheric gases is expanded by it. Within the tropics, the whole of the lower stratum of the atmosphere is kept warm by condensation of vapour, and extraordinary cases of condensation occur only at considerable elevations,—the diminution of pressure is therefore experienced over a wide extent, but in each particular part of that extent, only in a small degree.

While, in the arctic regions, the whole of each particular disturbance is within the view of a single observer, to another, within the tropics, it often appears to have an unlimited range, and seems to fill the whole atmospheric space to a great height. A consequence of this is, that, in any one place within the tropics, the barometer falls but little, seldom more than half an inch, though the cause of that fall may have been in energetic operation over a very extensive area, producing disturbances of the most formidable character in the upper regions.

ESSAY XVI.

On the Origin and Nature of the Forces that produce Storms.

Storms are strong winds, differing in degree and not in nature, from ordinary winds or moderate breezes. All the great movements of the atmosphere have their origin in vertical currents which are produced by certain known causes. These currents are fed from less or greater distances by horizontal currents, which press and flow towards the area of ascent, and the horizontal currents, whether they appear as moderate winds or storms, are thus produced by the ascending currents. It has, however, been shown that these vertical currents may at times produce sufficient rain to bend, and, at a distance, bring down the upper current of air and cause it to rush along the surface as a strong wind; but even then the heat liberated by condensation is the prime moving power, as that heat enabled the gases to carry up the rain until gravity came into action, and brought it down with a force proportioned to the expansion of the gases and the height from which the rain fell.

But it has been said by persons who object to the hypothesis here advanced, that the heat liberated in the atmosphere by the condensation of aqueous vapour, is not sufficient to lighten the air in the locality, to an extent that shall create a rapidly ascending current. That much latent heat is however really given out and made sensible, raising the temperature in the part where vapour is converted into water, is well known and universally admitted. It is familiarly experienced

when steam is condensed in our steam engines, and I have explained it more fully in previous essays.

It is not, however, often that the whole of the vapour that is in the atmosphere is condensed into water, or even so much of it as there commonly is in the condensor of the steam engine, seeing that the heat liberated in the atmosphere warms the part and the air that is in it, and thus stops or checks the condensation that is taking place. And it is not until the gases are made lighter through being warmed, and that the remaining vapour which is mingled with them is carried successively to greater elevations, that the whole or nearly the whole of the vapour existing in any locality is condensed.

In an atmospheric column that is ascending to higher regions, and in which condensation of vapour is taking place, the heat liberated reduces the cooling on an average to about one-half of what it would otherwise be; and two adjoining masses or atmospheric columns of the height of, say four thousand eight hundred yards, the one undisturbed by condensation, and the other having condensation going on within it, would have the temperatures as put down in the following table at the heights named, the dew-point and temperature at the surface of the earth being supposed to be both at 80°:—

Yards high.	Clear Air.	Clouded Air.	Difference.
4,800	32°	56°	24°
4,000	40°	60°	20°
3,000	50°	65°	15°
2,000	60°	70°	10°
1,000	70°	75°	5°
0	80°	80°	0°

Now it is evident that in the part of the atmosphere which is, say one thousand yards high, the clear air of the temperature of 70°, and of the density and weight which belong to that temperature, will have a tendency to press under and force up the adjoining column that has the higher temperature of 75°,

and which is therefore proportionately lighter; and the heavier column will press up the lighter with a force equal to the difference in the weights of the two, which is expressed in the numbers of the table by 5° of temperature. At the height of two thousand yards the difference of temperature in the two adjoining columns is 10°, and consequently the clear air at this height will have a tendency to press up the recently clouded air with a force expressed by the 10°. At three thousand yards high the superior weight of the clear air is 15°, and at four thousand eight hundred yards, when the freezing point in the clear air is reached, the difference in the two columns is no less than 24°. Thus we see, that on condensation taking place in any particular part of the atmosphere where the temperature and dew-point at the surface were at 80°, it would make that part so light as to permit it to be forced up by the adjoining heavier air at an increasing velocity, expressed by the numbers in the table which indicate the differences of the temperatures at the various heights. The commencement of this process would be slow, like the first movement of a railway carriage by a steam engine, but the velocity of the ascending current would increase with the difference of the temperatures of the two columns, until the aqueous vapour, the material furnishing the moving power, was exhausted. And as the velocity of the ascending current increased, so would the quantity of air that ascended within it increase; and the greater that increase the larger would be the quantity of the atmosphere that would press from adjoining parts, to fill the comparative vacuum that had been made by the condensation of the vapour. Here, then, we see that, under the circumstances described, a very energetic expanding power comes into action in the atmosphere, which reduces the weight of the air in the locality, whilst the adjoining heavier air that then presses and rushes in successively to fill the comparative vacuum, must produce a horizontal movement of air or a wind, the force and rapidity of which will be proportioned to the degree of vacuum created.

In the table that has been given, we have exhibited th cooling of the atmosphere through reduction of incumbe pressure, as it may be presumed to take place in a tropic region, to the height of only four thousand eight hundre yards, because, in air that was undisturbed by condensatio the temperature of 32°, or the freezing point, was the attained. But there is no reason that an ascending curren heated by condensation as it proceeded, and pressed upwar by fresh air rushing from below, should stop in its asce when it had reached the height of four thousand eight hu dred yards. On the contrary, the tendency of such a curren when supplied with sufficient vapour, is to permit its bein raised to far greater heights, and the difference in the ten perature of the two adjoining columns of clear and of cloude air, as long as condensation was proceeding, would still be th measure of power with which the heavier column would forc up the lighter. In the following table this difference is show up to a height of ten thousand yards:—

Yards high.	Clear Air.	Clouded Air.	Difference.
10,000	—20°	30°	50°
9,000	—10°	35°	45°
8,000	0°	40°	40°
7,000	10°	45°	35°
6,000	20°	50°	30°
5,000	30°	55°	25°
4,000	40°	60°	20°
3,000	50°	65°	15°
2,000	60°	70°	10°
1,000	70°	75°	5°
0	80°	80°	0°

Here we see that at the height of ten thousand yards from the surface of the earth, the difference of temperature between the clear and the clouded atmospheric columns produced by condensation of vapour, is no less than 50°; and with a force proportioned to that difference would the former column be

disposed to press up the latter, whilst the pressure upwards at the various intermediate heights would be as the numbers expressing the difference of temperature.

So far we have treated of the condensation of vapour carrying high temperature to great elevations; but at a certain stage of the process a new power comes into action. The undisturbed atmosphere was presumed to be of a lower temperature than 32°, above the height of four thousand eight hundred yards; any vapour, therefore, ascending above that height and entering the cold air that existed there, would be liable to be not only condensed into water, but to be frozen into snow. And were it not for the heat that is liberated by condensation, the vapour that penetrated this lofty region would be not only condensed, but frozen. And further, although condensation liberates much heat and keeps the temperature in the ascending column above the freezing point to a considerable height, yet at some greater elevation that point will be reached even within the comparatively warm ascending column. When this takes place and freezing commences within the column, we have a result differing from that which has been pointed out, as a new law then comes into operation.

When, through reduction of incumbent pressure, the ascending mass cools down to a temperature below 32°, the particles of water that had been formed by condensation are frozen; and in freezing, the liquid water gives out the latent heat that is always liberated when water is converted into ice. Now this liberated heat will have a tendency to keep up the temperature of the ascending column, and of the water and ice that are in it, and to prevent that temperature from falling below 32°. For it is well known that when a body of water is frozen by a moderate degree of cold, the process of freezing is slow, as the conversion of a part of the liquid into ice liberates heat enough to preserve the remainder in the form of water; and it requires time for the liberated heat to pass away before

a fresh portion of the water can be frozen by the existing degree of cold in the locality. In this way a mixed mass of water and ice may remain a considerable time at the temperature of 32°, in a part that is below that temperature, the heat given out to the water by freezing being nearly equal to that which is passing away; and this comparatively slow operation continues until all the water is frozen. The same process must take place in the atmosphere, when the particles of water produced by condensation of vapour are frozen into snow or hail, that is, into ice. As the ice is formed, the heat of liquidity of the water is set free, and the temperature of the locality and of the substances that are in it, is prevented sinking below 32° until all the water in the part is frozen. It follows from this, that when an ascending atmospheric column takes newly formed water that is within it to a height sufficient to freeze the water, the column for some time retains the temperature of 32°, while it is ascending successively into colder regions. The respective temperatures of the undisturbed cold air in the vicinity, and of the warmed ascending column that is passing through it, may, under these circumstances, be as shown in the following table, commencing from the temperature of zero at the surface; whilst the differences between the temperatures of the two airs would be those which are inserted in the column of the differences:—

Yards high.	Clear Air.	Clouded Air	Difference.
10,000	—100°	32°	132°
9,000	—90°	32°	122°
8,000	—80°	32°	112°
7,000	—70°	32°	102°
6,000	—60°	32°	92°
5,000	—50°	32°	82°
4,000	—40°	32°	72°
3,000	—30°	32°	62°
2,000	—20°	32°	52°
1,000	—10°	32°	42°
0	0°	32°	32°

It will be observed that in this table we presume that in clear and undisturbed air the temperature at the surface is at zero, which is found only in very cold localities; and as the temperature is presumed to be lower after the rate of 1° for every one hundred yards of ascent, at the height of ten thousand yards it will be 100° below zero. But as we presume that the heat liberated by condensation and freezing, as just explained, keeps the column in which these processes are taking place for some time at 32°, the difference between the two columns, at the full height named, must be for that time 132°. In so very cold a locality as that of which we are now treating, we know that any vapour which escaped from the surface of the earth and passed into the atmosphere, would be soon condensed; but the heat that would then be liberated would keep the product of that condensation in a liquid state, for some certain time, however short it might be, yet in such a part that heat would pass rapidly away, and the liquid would be frozen. The liberated heat of liquidity would, however, now preserve the cloud of liquid and frozen particles for some further time at 32°; and these two processes—first, condensation of vapour, and secondly, congelation of water—being successively and rapidly repeated in a column ascending to a great height, would keep the whole mass at 32°, as long as vapour remained to be condensed and frozen. And thus we find that the difference in the temperatures of the two adjoining parts indicated in the table, would be established for some time, however short it might be.

It has been often observed that, when the temperature near the surface of the earth has been greatly below the freezing point, upon a fall of snow occurring, the temperature has suddenly risen to 32°; and it commonly remains there as long as the snow continues falling. Now, it is known that this snow often descends from a considerable height in the atmosphere, and it is to be presumed that it brings the air, which is found to have a temperature of 32°, down with it.

The same fact is frequently observable in high latitudes, where the cold is intense. However low the surface temperature may have previously been, on a considerable quantity of snow falling it shows a tendency to rise to 32°. Such changes near the surface indicate that, in the part of the atmosphere in which the snow was formed from floating particles of water, whatever might be the height, the temperature in that part could not be below 32°.

It is not necessary to suppose that in cold latitudes, under the circumstances described, vapour shall be actually carried up to so great a height as ten thousand yards, or to any other particular height approaching it; but what has been observed in those latitudes gives reason to believe that snow and spiculæ of ice are there formed, from vapour, at greater elevations than has been hitherto imagined. Our object at present, however, is not to show precisely what occurs in such lofty regions, but to explain the kind of laws that govern the atmospheric changes that take place in them, and to point out that, to whatever extent these changes do occur, they must be under the control of the laws that have been exhibited.

It has been stated generally that the diminution of incumbent atmospheric pressure experienced at 100 yards of elevation from the surface reduces the temperature of dry or unclouded air one degree, whilst condensation of the vapour of saturated air, which is a result of that cooling, counteracts it to the extent of half a degree,—leaving the absolute reduction of the temperature of saturated air only half a degree for every hundred yards of height. This is, however, *an average* which is assumed, to reason upon, and is not to be taken as a correct statement of what actually takes place in the atmosphere whenever vapour is there condensed. The precise extent to which condensation of vapour will warm the locality and the gases that are in it, will depend upon the quantity of vapour that may be condensed there in a given time. When it is commenced in the lower regions, the locality

is warmed only in a small degree, and the adjoining heavier air will force up the lighter but slowly. When however the lighter air is forced further up, the condensation becomes more considerable, the warming greater, and the ascent more rapid, until the whole process is carried on with increased energy and rapidity; the difference between the temperatures of the heated and the adjoining unheated columns then becomes greater, and that difference determines the power with which the former is forced up by the latter. As the difference increases, the pressure of the cool air from below is augmented, and the rise of the lighter column is still more rapid, producing further condensation, a higher temperature for the elevation, and abundant rain. Under such circumstances, the temperature of an ascending column, instead of being lowered half a degree for every 100 yards of ascent, may possibly for some time remain undiminished, or even increased, notwithstanding the ascent, the diminished pressure, and the expansion consequent on that diminution.

According to published accounts, Mr. Walsh, of the Kew Observatory, ascended in a balloon from London on October the 2nd, 1852, leaving the earth at 45 minutes after 2 P.M. The temperatures found at different heights in the atmosphere are stated to have been as follows:—

At the surface of the earth at the time of starting............ 58° Fahrenheit;
And when a height of 1,500 feet was attained, it had sunk to 50° "

Had the air been undisturbed by condensation, it is presumed that the cooling would have been only 5°, whereas it was actually found to be so much as 8°. This low temperature probably was a consequence of the formation of a cumulous cloud in the region above, which removed some of the incumbent weight and caused increased expansion and cooling of the lower air, as explained in page 230. But on the balloon ascending an additional 1,900 feet, making a total height of 3,400 feet, the temperature, instead of sinking further, rose half a degree. Now in order to account for this

fact, we are obliged to presume that, after passing the height of 1,500 feet, the balloon entered a cumulous cloud which was then swelling and growing, and within which condensation was going on with sufficient energy to raise the temperature at the height of 3,400 feet to 50½ degrees.

At a further height of 1,000 feet, making a total elevation of 4,400 feet, the temperature, instead of falling, from the increased ascent and consequent expansion, rose 2 degrees more, making a temperature of 52½ degrees. But an additional fact is stated, which points at an explanation of what had occurred; the air is said to have been very damp at the time, and the aëronauts knew that they were enveloped in a cloud. Indeed, it is sufficiently evident, from the facts named, that condensation had been going on within the cloud, and we presume that it must have been so abundant as to have raised the temperature to 52½ degrees, because there appears to have been no other cause in operation to produce so high a temperature.

After this, the balloon seems to have ascended above the cloud and to have attained a height of 12,600 feet, and here the temperature was found to be 25°. Now, by taking the various heights named, and the temperatures actually found, and putting down the temperatures that it is presumed would be found at the same heights in an adjoining column which had been undisturbed by condensation of vapour, we shall have a view of parallel vertical columns of the atmosphere existing in a dry and undisturbed state, and also when disturbed by condensation:—

Height in feet.	Temperature of an undisturbed column of Air.	Temperature as observed.
12,400	16°	25°
4,400	43°	52½°
3,400	47°	50½°
1,500	53°	50°
0	58°	58°

From an inspection of these columns it appears that at a height of 1,500 feet, the air in the "observed" column had been cooled 3° beyond what was due to the height in undisturbed air, and thus great reduction of temperature is presumed to be attributable to the condensation of vapour above lightening the air, and allowing that which was below to expand and cool more than is due to the height. But at the height of 3,400 feet, where a temperature of, say, in whole numbers, 47°, was due to the elevation, it was found to be 50½°, showing that condensing vapour had, at this height, warmed the part 3½° above what its temperature would be when dry and at rest. At a height of 4,400 feet, the natural temperature of dry air would be, say 43°, but it was found by the aëronauts to be 9½° higher. And this, we are obliged to presume, was caused by a column of saturated air being forced upwards, so rapidly as to produce an amount of condensation of vapour that raised the temperature so high as 52½°. At the height of 12,400 feet, the natural state of dry air would have been a temperature of, say, 16°, whilst that found was 25°, and the inference is, that the temperature had been raised in the locality, by recent condensation, 9°.

In speaking of adjoining undisturbed air, it is not to be understood that there is, at some certain distance, air which is perfectly dry, or stagnant. In each actual occurrence the heavier air, that forces up the lighter, may only approximate to the undisturbed state; but the nearer the approximation the more complete will be the action in forcing up the lighter air. And it is so obvious that it is hardly necessary to state it, that if adjoining air should, from any cause, such as cloud evaporation, have been rendered heavier than the natural mean, its action would be still more effective. The important fact is, that air is rendered warm and light by condensation of vapour, and in proportion to that condensation, in one locality; while in other parts, within certain distances, other air more nearly or entirely retains its full natural weight, or may be a

little heavier, and, therefore, the latter forces up the former, and produces such results as have been described.

In 70° of north latitude, Messrs. Bravais and Lottin observed, at an elevation of between 1312 and 1640 feet, that the temperature rose as much as 10.8° Fahrenheit.*

From an account in the *Literary Gazette*, it appears that another ascent was made by Mr. Walsh on the 10th November, when the great height of 23,000 feet was reached. It is said that on this occasion the "temperature on leaving the garden was 50°, and at the greatest elevation it had fallen to 10¼° below zero, or through 60½°." Now a reduction of temperature of 1° for every 300 feet of elevation would have given a height of only 18,150 feet for a reduction of 60½° of temperature; whereas the height of 23,000 feet was attained when that degree of cold was experienced. The sinking of the temperature was therefore only 1° for about every 398 feet of elevation. And if 300 feet be sufficient to produce that effect in an undisturbed atmosphere, there must have been some disturbing cause in operation in the part at the time. Was it the formation of a cirrus cloud?

All the heights given were no doubt estimated from the state of the barometer; but it is evident that the height of the mercury of that instrument would be affected by the changes in the condition of the atmosphere, as well as from the elevation to which the instrument had been borne.†

* See Boussingault, page 656.

† "The difference in temperature between the valley and the tops of the mountains varies greatly, according to the amount of cloud, the presence or absence of mist on the mountain, and the height of the under surface of the stratus or cirrostratus above the valley. When the mountain is enveloped in mist quite down to its base, particularly if accompanied by deposition, the difference in temperature does not exceed 7 or 8 degrees; while under a clear and cloudless sky it amounts to 19 or 20 degrees."—Mr. Miller's "Meteorology of the Lake District of Cumberland, for 1852."

ESSAY XVII.

On the influence of Sun-heated Land in producing ascending Atmospheric Currents.

The Hadleyan theory of the trade-winds is founded upon the supposed influence of the rarefaction of the atmosphere of the torrid zone by the direct action of solar heat. The Rev. T. Milner, in his recent work, the "*Gallery of Nature,*" gives the explanation of that theory. He says—"As the sun is always vertical at some place within the tropics, the average temperature in that region is much higher than in latitudes to the north and south, and the incumbent air is thereby rarefied and expanded. The consequence is, that in obedience to hydrostatic laws masses of air are continually buoyed up from the surrounding surface, or swelled round the torrid zone in the form of a protuberant belt, the upper strata *flowing over* and *running off in streams towards the north and south,* where having been cooled and condensed, they descend and flow over the surface towards the equator, pouring in a perpetual current of air to supply the place of that buoyed up by the heat of the tropics."* And such is, in substance, the theory of winds which is to be found in all modern books that treat on Meteorology. Yet this theory is not only unsupported by specific facts, but is directly at variance with many of them; nearly the whole of those that have been collected, having a bearing on the subject, tending to prove, not the truth, but the falsity of the theory. That the surface of the earth being in parts heated by the sun to a high temperature, will to some

* Page 440.

extent communicate that temperature to the air resting upon it, which will then rise, allowing cool air to flow in and supply its place, is, to a small extent, undoubtedly true: but that this kind of heating of the air produces the important effects ascribed to it in the received theory of winds, is not shown by reference to any known facts, nor by any just inference from those that have a bearing on the subject. It is therefore to be viewed only as a plausible conjecture, which has been advanced and adopted in the absence of real knowledge of the subject.

I have in former papers shown that the influence, on the atmosphere, of such heating of the land as is referred to, is feeble and incapable of producing the strong winds, including those called the trade-winds that blow in many parts of the world; but it is highly desirable that we should go more fully into the subject, and trace more particularly the real effects of heating the surface of land by the sun that are produced on the air resting upon the land. It must be observed that it is not merely the geographical position of the tropics that is supposed to cause the rise of the air, but the high temperature of the surface of the land, and of the air resting on it, as a consequence of that position. It therefore follows that where the surface is the most heated by direct solar influence, the effect spoken of should be experienced in the highest degree; and the large areas on the earth's surface which are the most heated, should have the air over them the most swelled and buoyed up, allowing cold air to flow towards them below in the most palpable and decided manner. Now there are a number of such places respecting which we have tolerably full information, and all that is necessary to be done, is, that we should collect that information, and ascertain the nature of the evidence which it furnishes respecting the truth or the falsity of the theory under consideration.

It is well known that it is not either upon, or near to, the equator that the most highly sun-heated land is found, or

where such lands exist to the greatest extent, although most of them are within or near to the tropics; some, however, extending considerably beyond that limit. From the equator up to the latitude of 30°, or in certain parts to 40° north, in the summer, much sun-heated land is found, including the deserts of Arabia and Persia; and an inquiry into the state of the air over these deserts at that season, and its various movements about them, will enable us to judge of the influence of direct solar heating of the land on the atmosphere which rests upon it. The deserts of Bokhara and Tartary extend far north, and they are heated to a very high temperature in the summer,—we may therefore begin by adverting to the influence of direct solar heat on their atmospheres. They may be considered as extending from the Sea of Aral, in 45° north, towards the south. Accounts pretty generally agree in representing the summer temperature in these parts as reaching to 100° of Fahrenheit. Burnes, in his *Travels*, says—"After having passed the Oxus, the country was entirely destitute of water, but the wind blew steadily from the north, (the hot country in the summer,) from which quarter it blows constantly,—nor do I believe that it would be possible to traverse this tract, in the summer, if it ceased to blow." Yet nearly south of this part there exist extensive ranges of mountains covered with snow during the whole of the summer, which of course have a very low temperature. Here, then, if there was truth in the theory under consideration, we might expect to find air ascending from the heated surface, and permitting other air to flow into its place from colder districts. But not a breath of air appears to pass from the parts that are covered with snow to the hot land of the desert. On the contrary the wind blows steadily from the north, which part is highly heated at the time;—that is, the wind blows from a direction the opposite of that in which the cold exists. Now what evidence do these facts present that the air resting upon this hot desert is heated by it, until that air swells, rises,

and flows over in upper regions? Certainly none! they give no countenance to that theory.

It may be imagined, however, that the atmosphere, though it does not ascend here, rises from surface-heated land, somewhere still further south;—but this, we shall find on inquiry, is not the fact. For in the Persian deserts, to the south, as well as across the deserts of Beloochistan, the wind continues to blow from the heated north during the whole summer, producing the extreme dryness that is found there. At Bagdad and Bushire, the thermometer sometimes stands at 135°, yet no fact can be traced in this locality to countenance the supposition that any atmospheric current ascends from these heated parts.

The great Desert of Arabia, a considerable portion of which is west of Persia, but a large part south of it, and much of it lying within the northern tropic, presents the same general features as the more northern and eastern deserts just spoken of. It is not, however, to be supposed that the winds, as they pass over these extensive countries, are never disturbed in their course to any extent by local influences. No doubt mountains or hills will and do more or less affect them, and cause local deviations from their general course. But the great cause which produces the principal wind seems to have sufficient power to overcome these local influences, and to determine the general movement of the mass of the atmosphere.

The land in the desert of Arabia is probably raised to as high a temperature, by the direct action of the solar rays, as any portion of the surface of the earth; and if the mass of air resting on the earth could be raised and made to overflow by mere surface-heating, it would undoubtedly ascend here energetically, and flow away in the upper regions, leaving other air to come in below from contiguous parts, and particnlarly from the comparatively cool adjoining Arabian Sea. But what are the facts of the case? Why the general wind continues to blow over the heated land, until it passes to and

over the Arabian Sea:—that is, it moves from a hot surface to a cool one. In fact, this large mass of air, coming from the heated lands named, makes its way over the hot desert and round the bases of the snowy mountains of Hindoo-Koosh and Affghanistan,—passes to the comparatively cool water of the Persian Gulf and Arabian Sea, where it appears to take up a partial supply of aqueous vapour, and it finally rushes over the plains of Hindoostan to the Himalaya Mountains, where it really does ascend. These plains, however, are not then highly heated by the direct action of the sun upon them, as the surfaces of the desert were over which the wind had passed,—the plains of Hindoostan being at this season screened from the direct solar rays by a thick canopy of clouds, the country being generally, though not universally, deluged by rain; the exception being found about the mouth of the Indus and in Cutch, over which the dry air from the deserts passes.

These facts show that the cause of the continued flow of air over the deserts that have been named, is to be found in the large amount of condensation of vapour that is taking place against the lofty Himalaya Mountains, which vapour is known to have been brought from the wide expanse of the Indian Ocean; and its condensation appears to be sufficient to produce a comparative vacuum; and to create ascending currents powerful enough to draw air from the remote distances that have been described. The moving mass of air constitutes a general north wind in the deserts of Bokhara and Persia, and a north-west wind over Arabia, and it is turned into a west wind in its passage across the Arabian Sea, these directions being evidently determined by the large amount of condensation that is taking place against the Himalaya Mountains. In the whole of the countries traversed, we have, then, evidence that dry solar heating of air does not produce ascending atmospheric currents, and consequent horizontal winds. We also see what does produce them,—that they are produced by condensation of aqueous vapour. The evidence may therefore

be considered strong as far as respects the localities that have been named.

But the great Desert of Northern Africa is the part generally pointed out by those who say that the heat of dry land produces important ascending currents in the atmosphere. Respecting this desert, "Dr. Oudney, in the course of his long journey from Tripoli to Lake Tchad, estimated the elevation of the southern Sahara at 1,637 feet. The French engineer, Fournel, has, by careful barometric measurements, based on corresponding observations, made it probable that a part of the northern desert is below the level of the sea. Between Biscara and Sidi Ocba the ground is only 243 feet above the level of the sea."* And Milner says—"From the west coast of Africa, and between Morocco on the north, and the Senegal River on the south, this wilderness extends easterly to the Red Sea. It embraces a space of more than 46° of longitude and 15° of latitude, or a length of 3,000 miles by a breadth of 1,000. A large extent of the Sahara is a dead level, but low sand hills, wadies or valleys, and projecting rocks are frequent."† It is stated to be "like an immense furnace, warming all the regions on the Mediterranean, in the south of Europe and the west of Asia."

It will, however, be found, on inquiry being made, that the facts relating to this desert present no evidence to justify such a statement. A moderate flow of air from the north appears at times to pass over Algiers and Tripoli to the desert, in a fluctuating and irregular way; but it passes over the whole desert, leaving it nearly destitute of water, and probably in some way, not open to observation at present, feeds the north-east trade-wind of the Atlantic, which is said to have its origin over the sea not far from the desert. But the only winds that have a decided character in or about this extensive area, are the north wind that blows up the valley of the Nile, and the Harmattan, which issues from the desert and is lost in the Atlantic.

* Aspects of Nature (Humboldt's), p. 115 † Milner, p. 226

That which blows up the Nile begins in the month of June, a time when the desert is much heated; and the wind is known to continue blowing up the river as far as Abyssinia. Speaking of it a compiler says—"The mists which are exhaled from the Mediterranean by heat, and which frequently obscure the Egyptian sky, are carried by the north winds over the flat country without interruption, until they are arrested by the mountains of central Africa."* But this part of central Africa is, as compared with the desert, a cold country, being much elevated;—the wind, therefore, blows along a border of the desert to feed an ascending current in a distant part. It may, indeed, as stated by Lizars, be distinctly traced as coming from the Mediterranean Sea, and the countries beyond it;—and in blowing up the valley of the Nile it passes by the imagined vacuum over the desert, and proceeds to the elevated land of Abyssinia, where we find again, as we did among the Himalaya Mountains, that at the same time rain falls in great abundance, as is shown by the rise of the river shortly afterwards. But if the hot Sahara heated the air that is upon it, and made it swell and ascend to the higher regions, allowing cool air to flow in below to supply its place, in the way that has been alleged, this current of air which now goes up the Nile would undoubtedly be drawn westward towards the interior of the desert to feed the ascending current: and as it is not so drawn, it is to be presumed that no such current exists over the desert.

The accounts which we have of other winds that occasionally blow on the same side of Sahara represent them as blowing from the west,—that is, from the desert towards the valley of the Nile. This is so decidedly the prevalent direction of these winds, as to cause them to carry the loose sands of the desert towards the river. It is confidently said that the sand thus brought has been long covering the land on the west side of the Nile, and converting it into desert. Now if air ascended from the desert, such a wind could not exist; it is therefore

* Lizars' Atlas, p. 262.

also evidence in favour of the non-existence of an ascending current within the desert.

Another wind is sometimes encountered in this part of the world, which is thus described in a popular geographical work:—"Egypt is liable in spring, for a period of fifty days, to the terrible wind of the desert called 'the Simoom,' which from its intense heat and dryness threatens, when long continued, the extinction of animal life. It seldom continues, however, above three days." The wind here described is, there can be no doubt, caused by a local ascending current, as it raises large masses of the sand of the desert to a considerable height. It is, however, always accompanied by a thick cloud, which intercepts the light of the sun to such an extent as to bring on darkness almost equal to that of night; there must, therefore, notwithstanding the dryness of the air below, be a considerable amount of condensation of vapour taking place above in some part of the atmosphere, in order to produce the cloud. One writer, describing this wind, says—"We knew not where we were, and could not distinguish any thing at the distance of a foot. The sand wrapped us in darkness like a fog, and the sky and the earth seemed confounded and blended together."* The particular cause of this extraordinary wind we have no means of determining, the requisite meteorological information not having been furnished, but it is said to come *from* the desert, and to continue but for a short time; it cannot therefore be taken as evidence of the existence of such an ascending current within the desert as is under consideration. Indeed, the evidence *that it furnishes is in favour of the non-existence of such currents, and of the means of producing them.* If *sufficient vapour* existed in the part, it would evidently be carried up by the Simoom, and rain would be produced as in rainy localities.

"The Harmattan" is a wind that blows on the surface of the desert from the interior towards the Atlantic Ocean.

* Caillé.

passing for some distance over the sea. It is irregular in its occurrence, although more frequent in our winter than in other parts of the year. It blows with considerable force and often lasts for a number of days. The following is the description of this wind by Milner. He says—"The Harmattan, a periodical wind from the desert, differs remarkably from the Simoom. It blows from the interior of the great Sahara, from the north-east over Senegambia and Guinea to that part of the coast of Africa that is between Cape Verde, in fifteen degrees of north latitude, and Cape Lopez, in one degree of south latitude, a coast line of upwards of 2,000 miles. It occurs during December, January, and February, generally three or four times in that season. It comes on indiscriminately at any hour of the day, at any time of the tide, or at any period of the moon, continuing sometimes only a day or two, at other times five or six days, and it has been known to last for upwards of a fortnight. It blows out to sea for ten or twelve leagues. Extreme dryness is another property of the Harmattan; no dew falls during its continuance, nor is there the least appearance of moisture in the atmosphere."

This account of the Harmattan shows that it blows over the surface of the earth from the desert, which is the reverse of what would take place if heated air were ascending to the higher regions, and overflowing to adjoining countries. It is therefore evidence against the received theory.

Since the above was read to the Literary and Philosophical Society of Manchester, I have been informed by a gentleman who has resided for a considerable time on the coast where this wind blows, that the inhabitants of the country confidently assert that a violent tornado in the vicinity always precedes the Harmattan. It is spoken of by them as a well known fact, that "*the Harmattan always comes in with a Tornado;*" there is, therefore, no reason to doubt the connection of the two phenomena. Evaporation in this hot climate charges the

stagnant atmosphere over the sea with vapour up to the point of saturation, when some slight disturbance, at a moderate distance from the desert, sends a portion of the lower air into a higher region, and condensation of a part of the vapour is begun. An ascending current is produced, of a strength proportioned to the quantity of vapour that is carried up: the adjoining saturated air around then rushes into the vacuum that is created, which enlarges its area and extends over the whole locality, until the vapour is borne to the upper regions, where it is condensed and furnishes deluges of rain. The great vacuum which is thus formed in the atmosphere, being near to the desert, the dry air over the desert presses into it, and will be disposed to follow it to a distance over the sea, until the supply of vapour from the sea is exhausted.

Teneriffe, one of the Canary Islands, is to the north of this locality where the Harmattan blows, and Humboldt says that when he was on the Peak of that island, a west wind blew with violence, though the island below was under the ordinary influence of the north-east trade wind. But this shows a state of things just the reverse of what would be found if heated air ascended from the surface of the desert, as then there would be a west wind blowing below from the cool sea towards the heated land, and the air which rose from the desert would overflow from it towards the sea in the higher regions. Thus all the facts of the case that we have passed under review are strikingly at variance with the common theory of ascending currents from sun-heated land, giving no countenance to that theory. It may be observed that in this part of the Atlantic Ocean the water comes from the north, it being the place of termination of the gulf stream which flows from Newfoundland by Ireland; and no continued wind can be traced, even in the summer, blowing from this cool sea to the heated desert. The slight winds that are sometimes found here blow from the desert to the sea:—this is shown by the fine sand that is borne by the air to the islands and the ocean beyond them.

Captain Fitzroy says that "at St. Jago the wind being always from the north or east from December to June, a ship can moor as close to the weather shore as may be convenient; but from July to October no vessel should deem the Bay of Porto Praya secure, or anchor near the shore, because southerly gales sometimes blow with great strength."* Thus we see that all winds are found to blow in this part except westerly, which would be the principal, if not the only one, if air ascended from the desert.

There is another wind which must not be passed unnoticed. It blows more or less throughout the year from the west, but with some fluctuation in its direction, from the Gulf of Guinea towards the main land of Africa. It passes, however, over the equatorial parts of the country towards a mountainous region where heavy rains fall, and not towards the heated desert.

The imperfect accounts which we have of the interior of this great area of stones and sand state that, although the ground is greatly heated by the sun during the day, at night its temperature sinks to a low degree, as compared with that of the day. The mass of the atmosphere is therefore probably not greatly heated. It appears from many facts that the solar heat which is accumulated near the ground in the day is rapidly dissipated by radiation through a clear sky at night; and the mean temperature of the air at a moderate height, if taken at each of the twenty-four hours, would probably be found not to be high. In those parts of the desert that are near to the Mediterranean, heavy dew moistens the ground, from which the deceptive mirage, so often described, is probably produced. But more in the interior no dew appears, even during the great cold of the nights, the air therefore must be very dry, and the sky is said to be generally without clouds.

A wind is occasionally felt on the south-west coast of Italy, which, as it is said to come from Africa, it is necessary to

* Fitzroy's Voyages, p. 51.

notice. The following account of it is from Milner. He says—"It is a hot south-east wind, prevailing in the Mediterranean, in Italy and Sicily, but felt most violently in the country around Naples and at Palermo. It sometimes commences faintly about the summer solstice, but blows occasionally with great force in the month of July." "There can be little doubt (Milner continues) that this south-east wind sweeps across the Mediterranean from the shores of Africa." But it comes as a lower wind; and therefore as evidence that Africa heats air and causes it to ascend, it entirely fails.

If air from the Mediterranean Sea or the Atlantic Ocean flowed freely towards the interior of Africa, where it became heated and ascended to a considerable height in the atmospheric space, it would by that ascent expand and cool, and having taken up vapour from the sea, that vapour would be cooled by the gases, and would produce cloud and rain. It is because there is not a sufficient swelling and rising that the country is so dry. There is no land sufficiently elevated to force the air to such a height as shall bring on condensation, and create ascending currents that will permit air to pass on the surface as a wind, as it does up the Nile, to the rainy district of Abyssinia.

It is, however, only proper that the following passage which I have recently met with in Humboldt's *Aspects of Nature*, vol. i., p. 61, should be given. This eminent philosopher says—"It is a remarkable phenomenon, well known among sailors, that in the vicinity of the African coast, between the Canaries and the Cape de Verde Islands, and particularly between Cape Bojador and the mouth of the Senegal, a west wind often takes the place of the general east or trade-wind of the tropics. It is the wide expanse of the desert of Sahara which causes this westerly wind. The air over the heated sandy plain becomes rarefied and ascends,—the air from the sea rushing in to supply the void so formed, and thus there *sometimes* arises a west wind adverse to ships bound to the

American coast, which are made in this manner to feel the vicinity of the heat-radiating desert, without even seeing the Continent to which it belongs. The changes of land and sea breezes, which blow alternately at certain hours of the day or night on all coasts, are due to the same cause."

From this passage it is probable that the learned writer of it was so exclusively and entirely impressed with the idea that air *must* rise from heated land, as to induce him to refer facts which he met with, or even heard of, to it as the cause, without making further inquiry on the subject. But if heated land in the Sahara really produced such an effect as that ascribed to it, should we have only such meagre hearsay evidence of it as that given? The general wind of the part is fully admitted to be the eastern trade-wind, and it is said that there only *sometimes* arises a west wind,—which is characterised as a "remarkable phenomenon." Now it is well known that winds blow to some extent on all coasts from the sea to the land, because there are generally some obstructions, or elevations of the land, not far from the sea, up which air ascends and forms cloud, and where more or less rain is produced. But such winds are less frequent and more feeble on this than on other coasts: indeed they are so much exceptions to the general movement of the atmosphere in the locality as to be unnoticed by all the compilers and navigators I have happened to meet with. It is, however, sufficiently evident that if this desert really acted on the atmosphere in the way that is supposed, the west wind would be nearly always blowing, and during the summer with great strength, instead of being such an exception as to have almost escaped observation. The desert, on this part of the coast, is but little known, but on some maps hills or mountains are marked, and there may be such sufficiently high to produce occasional rain. This is the more likely as the mouths of some short rivers are marked on the maps, as entering the sea in this part, such as the river Cyprian, in 22° of latitude, and the river Del Oura, near the

tropic, and rain must have fallen to supply the water that flows down these rivers. But, as Humboldt states that the cause of this west wind is the same as that which produces land and sea breezes on coasts, and as there are no accounts of daily sea breezes along the coasts of this desert, though they are known to exist to the south of it,—even the authority of this eminent philosopher proves little more than that, in the great extent and variety of his multifarious inquiries, he has sometimes adopted the general conclusions which he found in books, without carefully examining the foundations on which they rest.

If the Abyssinian mountains extended across the desert to the Atlas range, the air which now goes to Abyssinia would doubtless in part flow towards the imagined mountains; and winds similar to those which now blow from the Gulf of Guinea might then rush from the Canary Islands, across the present dry deserts, to the same elevations. There would then be not only ascending currents in the air, but rain to water the earth; and, if the mountains were lofty, large rivers might flow through the deserts to the seas, as they now flow from the Abyssinian and Himalayan Mountains.

The tropical seas from which vapour is principally raised are in the Pacific, the Indian, and the Atlantic oceans. That which comes from the first of these oceans is condensed mostly among the mountains of the eastern archipelago,—from the second, against the Himalaya range,—and from the third, against the cordilleras of the Andes; and when condensation is taking place energetically among any of these mountains, the air rushes towards them from the adjoining seas, and constitutes a wind, strong in proportion to the amount of condensation of vapour in the part.

But to enable us to reason upon the real causes which are at present in operation to produce such winds, let us suppose that a broad belt of the equatorial land all round the globe,—say fifteen or twenty degrees on each side of the equator,

including the Andes, the eastern archipelago, and the mountains of central Africa,—was low and flat, as the valley of the Amazon is now; and that mountains similar to those at present about the parts of the equator just named extended from 20° north to much beyond the tropic, as the Himalayas do,—there being at the same time no other mountains in the south,—and then endeavour to conceive how the atmosphere about the equator would be affected by such a state of things.

From the evidence already adduced, we may infer that evaporation would take place from the tropical seas as at present, and the air over them would be saturated with vapour. But as there would be no elevated land contiguous to the equator or near those seas, excepting the supposed mountains, the slight disturbances which are always occurring in the atmosphere would force some of this vapour up the northern mountains, as it is now forced up the Himalayas, and thereby produce such ascending currents against their sides as would draw all the air and vapour from the tropical seas towards themselves. Winds would then blow from the tropical seas to the mountains, leaving the imagined low belt of tropical land dry desert, like to the Sahara. The temperature of the air over the low land might possibly reach 120° or 140°; yet there is no reason to suppose that such heated air would there rise and overflow, as there would be no condensation of vapour going on in it. But while the temperature of the air near to the mountains would rise probably not much higher than 80°, a temperature very high for the height in the atmosphere would be carried to great elevations, whilst the heat over the low tropical land would be confined to a moderate stratum of air near the surface of the earth.

We have facts, similar in their nature to those just given hypothetically, in the existing state of things near the tropics. The imaginary tropical low lands would be just such as now exist in Arabia and Africa, and the mountains would be similar to the Himalaya range. And it would not be more

surprising that vapour should then pass from the tropical Atlantic seas to be condensed against mountains in the north, than it is that it now passes from the southern, as well as from the northern Indian ocean, to the Himalayas. At present, in the summer monsoon of the Indian ocean, vapour passes from south to north, from Madagascar to the Himalaya range, through 50 degrees of latitude, and it might equally well pass over the tropical Atlantic to mountains 30 degrees north. But this would prove by the evidence of facts that direct solar heating within the tropics did not cause the air to swell and ascend and flow over in the higher regions, any more than it does now from the deserts of Arabia and Africa.

ESSAY XVIII.

On the Formation and Classification of Clouds.

Clouds of all kinds are products of vapour which has been primarily furnished by evaporation from the surface of the globe. The dense Stratus, generally hovering near to the surface and apparently stationary,—the swelling Cumulus, piling mountain upon mountain, surpassing in their grandeur terrestrial elevations, as well as the airy-looking Cirrus,—are all products of that vapour which, in an invisible state, is furnished from the surface of the globe to the atmospheric space.

Attempts have been made to classify the clouds, but those attempts have been founded almost entirely on their shapes or appearances, having no reference to the manner in which they are produced from the invisible vapour. The very different forms, however, which clouds assume may reasonably be supposed to result from the different processes that take place in the atmosphere through the condensation of the vapour that exists in it, or from the various circumstances that are connected with that condensation. And if we could follow those circumstances and trace the different processes that are in operation from the formation of the vapour by evaporation at the surface of the earth, until it appears in the various clouds that are presented to the view in the higher, as well as the lower, regions of the air, we might become better able to account for their different aspects; whilst the peculiar appearances which they exhibit, might possibly suggest ideas respecting the nature of the processes which produced them.

In describing these bodies, Milner says—"The forms assumed by the clouds are so infinitely diversified, as to render it apparently hopeless to attempt their arrangement in a few general modifications. But a classification has been made with some success, which reduces these varied aërial objects into seven genera." He then proceeds to give the seven names that have been applied by Howard, and also those of Foster.

FIRST. "*The Cirrus, or Curl-cloud.*" "This form of cloud," he says, "exhibits light flexuous or diverging fibres, sometimes shooting out from a nucleus in all directions, resembling a lock of hair or a crest of feathers." It will be perceived that the name of this kind of cloud, "hair or curl-cloud," as well as the description given, relates entirely to its form. It is generally seen in the higher regions of the air.

SECONDLY. "*The Cumulus, or Stacken-cloud.*" "This modification of cloud," says Milner, "occurs in the lower regions of the atmosphere, and is easily recognised. It consists of a vast hemispherical heap of vapour rising gradually from an irregular horizontal base. Hence the names Cumulus, a pile or heap, and Stacken-cloud, a number of detached clouds stacked into one large and elevated fabric." This cloud is evidently named from its peculiar appearance in the sky.

THIRDLY. "*Stratus, or Fall-cloud.*" This is stated to be "a bed or covering of the surface of the earth, produced by subsidence of vapour in the atmosphere." These names also express the form, excepting when the subsidence of vapour is spoken of, and this subsidence is distinguishable by observers, only because the cloud exists near the surface. No doubt other clouds sometimes subside still more than this, but they are too high to allow the movement to be distinguished. These three names, even according to this classification, designate the primary clouds, the other four which follow being either compounds, or certain modifications of the primaries, as—

FOURTHLY. "*Cirro-Cumulus—Sonder-cloud.*" "This is of an intermediate nature between the Cirrus and the Cumulus."

FIFTHLY. "*Cirro-Stratus,—Wane-cloud.*" These names point to the origin and form of the cloud, and they indicate that it is produced from portions of the Cirrus and Stratus, dissolving or waning in the atmosphere.

SIXTHLY. "*Cumulo-Stratus—Twain-cloud.*" This is formed by Cumuli uniting and producing a ridge, or a cluster of mountains of cloud, looking like the Stratus in the lower part.

SEVENTHLY. "*Nimbus, or Rain-cloud.*" "Any of the preceding modifications of cloud," says Milner, "may so increase as to veil the sky completely, and put on the appearance of density from which an experienced observer will augur rain. But they frequently dissolve without any shower, and no rain falls till another modification has been experienced. After exhibiting a great increase of density and assuming a lowering aspect, the blackness or darkness is followed by a lighter shade, evidencing a fresh disposition of the aqueous particles in the cloud, or the formation of the Nimbus from which rain falls."

These are the names and descriptions of the different clouds that are given by Milner, and excepting those portions which relate to their forms they are exceedingly meagre and obscure. In giving these names no attempt is made to indicate the nature of the changes that are taking place in the atmosphere to produce the various forms:—the most that is stated in that respect being, that a lighter shade following darkness evidences a fresh disposition of the aqueous particles; this fresh disposition being the formation of rain. Nothing is said as to the mode in which the rain is formed, or of the laws of nature that are in operation preparatory to, or during its formation,—leaving us to suppose that nothing is known. Indeed, with the information that is to be found in standard works on Meteorology, it was not practicable to do more on the subject than has been done. But this is exceedingly unsatisfactory, and renders it highly desirable that efforts should be made to trace, as far as we are able, the working

of those laws through the various formations of cloud that are successively exhibited in the higher, as well as in the lower regions of the atmosphere. Cloud being evidently a result of condensation of vapour—when that cloud presents itself to the eye in certain forms or appearances, it is to be presumed that each particular shape of the cloud indicates a peculiarity in the process of condensation of the vapour that is in the part,—or of the evaporation of the cloud that had been previously formed,—which peculiarity may possibly, to a considerable extent, be discovered and exhibited; thus revealing to us the immediate cause of the clouds taking respectively the particular forms which they present to the sight.

As has been stated, evaporation from the surface of the globe primarily furnishes the vapour which exists in the atmosphere, and it is produced by a union of heat and water,—whilst condensation of the vapour is effected by abstraction of heat from it,—thus restoring it to the liquid state: the two processes, therefore, cannot be going on in the same place at the same time. When vapour rises from the surface of water, it is perfectly transparent, but provided that the temperature of the space into which it is passing be sufficiently low, a part of that vapour may be very soon condensed, at any height above the surface, by the abstraction of heat from it. In the autumn, in those parts of the world where the nights are cold, vapour which rises from the surface of comparatively warm water, in rivers or lakes, is condensed at only a small distance from the water, and it constitutes the mist or fog that is often seen, at that season of the year, over rivers and lakes. A stratum of this mist may be formed, of a certain thickness, dependent on the warmth of the water, and the coldness of the atmosphere. But at the upper surface of this stratum the particles of water that constitute the mist may be re-converted into vapour by evaporation, and thus a double evaporation may be going on at the same time, one at

the surface of the earth, and the other from the upper surface of the mist, and the general result may be that additional vapour will be thrown into the higher parts of the atmosphere. This double process may sometimes be traced as going on very near to the surface of the earth, where a thin stratum of mist is formed which is soon afterwards dissolved by evaporation and sent into the upper regions in a transparent state. Such a stratum, only a few inches in thickness, in level parts, constitutes the "Mirage" which is seen in many flat countries when the sun has much heated a moist surface.

In higher parts of the atmosphere a second evaporation during the hotter part of the day is not an uncommon occurrence. When the sun greatly heats the surface of moist land, any water that may be in the land is evaporated with energy, and the vapour then produced, by its elasticity, ascends into the atmospheric space above. But it may there meet with cool air, and be in part condensed, and form incipient cloud. The sun, however, shining strongly through a clear sky above, now acts on the upper portion of this thin cloud, and frequently evaporates it, sending the vapour to a greater height; and this may take place successively at different heights in the atmosphere, as long as the sun retains sufficient power to re-dissolve the incipient cloud soon after it is formed. But in the tropical and temperate regions, when the air in the higher parts becomes fully saturated with vapour, whilst more continues rising from the surface, cloud is accumulated until it becomes dense and dark. The sun, not being then able to dissolve the upper surface of the cloud, as fast as fresh cloud forms below—the cloud increases in thickness and extent, constituting a stratum at a particular elevation. In a short time afterwards, but while the surface is still heated by the solar rays, little protuberances are perceived on the upper edge of the stratum, like round buttons, or little cones, which increase in size and at last grow to hills of cloud. Now this growing is the result of a

process which is very important in atmospheric phenomena. It is a consequence of the condensation of vapour that is taking place within the body of the cloud, heating the gases with which it is intermixed. And the gases, being thus heated, expand,—a portion of their weight is removed to adjoining parts, and they become lighter and are pressed up by the unheated gases that are below, and thus a chimney is formed in each of the swellings, up which the heated air ascends, taking vapour with it to be condensed in the higher regions, where it forms that beautiful object a Cumulous Cloud. Should the supply of vapour from below continue sufficiently abundant, each of these cumuli may increase in size and become a mountain of cloud, and a number of them being blended together they constitute those soft and fleecy, yet sublime objects, that often appear in summer and autumn as piled up mountains of vapour and cloud.

These latter clouds are then formed, not merely by condensation of vapour producing a mass of mist, but by the heat which is liberated in the condensation of the vapour making the atmospheric gases light in the locality, and causing them to ascend and take with them in their ascent the remaining vapour and the mist with which they are intermixed. The local ascending current that is thus formed in the air is a new process,—and produces a new form of cloud, and the name of Cumulus may be considered as designating that which is thus formed. The Stratus may therefore be viewed as the product of simple condensation of vapour, which condensation has not materially disturbed the atmospheric gases,—whilst the Cumulus is produced by those gases being sufficiently heated to cause them to be forced upwards in separate streams or currents, carrying vapour into higher regions, there to be condensed by the cold belonging to the superior elevation;—and these latter processes may continue as long as the sun exerts superior power in evaporating water on the surface of the earth.

As the power of the sun declines, the Cumuli,—no longer fed with abundance of vapour from below, cease to grow; but their interior mass having been warmed by condensation may then float away to other, and it may be to higher parts of the atmosphere. This is, in fact, a common effect of the daily formation of cumuli. On the decline of the sun and the consequent cessation of a copious supply of vapour from below, the clouds cease to grow in size, but the mass being warmer, and therefore somewhat lighter than the adjoining clear air, the whole rises and frequently floats away like a balloon, to a distant part, soon, however, losing some of the sharpness of outline which distinguishes freshly-formed cumuli, and showing a tendency to break up into separate portions. These floating clouds are sometimes called broken cumuli, and they often continue to float in fragments with ragged edges, occasionally covering nearly the whole of the sky during the afternoon.

Cumuli are often produced, as just described, in the open atmospheric space, but they are still more frequently formed against the sides, or over the ridges, of mountains. The vapour that is daily produced from the sea by the sun, is, by any horizontal movement of the air, carried over the surface of the earth;—and should it encounter elevated land, is by its inertia forced to ascend the land, until it reaches a height sufficient to cool and condense some of it. The heat of condensation now causes the air to ascend still higher, and more vapour flowing in—more is condensed, cumuli are then formed, and they frequently float over the sides or the tops of mountains, exhibiting a stream of massive clouds extending to a great distance from the place of their formation;—gradually, however, losing their well-defined outlines, and becoming ragged and broken cumuli.

But the higher parts of the atmosphere have but little vapour, or are comparatively dry, when they have not been rendered moist by cloud evaporation; the outer portions of

these cumuli are therefore generally soon diminished in size by evaporation, and the greater the height the cloud had attained, the drier will be the air in which it floats, and the more energetic the evaporation from it, until it is at last dissolved. Evaporation is however always a cooling process, and in the particular locality where it is taking place in the atmosphere, it cools the gases that are present, when they become heavier and descend. The outer parts of the cloud being in drier air than the inner portions, are the soonest cooled by evaporation, and they descend sooner than the central part, within which evaporation may not indeed then have commenced, owing to the part being yet saturated with vapour. The result is, that the portions of the cloud which have been cooled sink and move away from the rest, and the whole mass is frequently stretched out like a drawn fleece of cotton wool, presenting to the view those attenuated streams of white mist or thin cloud, called Mare's tails, that are often seen extending over a large portion of the heavens. And as the descent of one part of the cloud, that has been cooled and made heavier by evaporation, may force up another part, these mare's tails may in their movements make various turns. Portions of the same mass appear sometimes to be drawn in different directions, changing from their first course and moving in a second, according to the descents or ascents of the different parts. These mare's tails show that the daily clouds which have been borne to the higher regions of the atmosphere are dissolving, and that no fresh cloud is forming in the locality.

When a stream of cumuli has covered the sky, it is sometimes seen, particularly in the afternoon, that the whole of it changes from a continuous mass to a number of discs or patches, with intervening portions of the sky nearly transparent;—it has been called a Mackerel sky, from the resemblance of the patches to the marks on the backs of mackerel. From the manner in which the change takes place, it is not

unlikely that before the mass was broken up, evaporation from surfaces of the cloud cooled portions of the gases, and these portions, then becoming heavier, descended,—leaving the unevaporated parts in detached patches above them; and, the evaporation continuing from the remaining portions, in due time reduces their size and at last dissolves the whole.

There are other occasional appearances in the sky which indicate the existence there of floating mist or incipient cloud. The sun is frequently dimmed in such a way as can be accounted for only on the supposition that varying quantities of floating matter interpose between it and the surface of the earth; the moon is similarly affected at night, both the luminaries occasionally exhibiting striking appearances called halos round their discs. In the northern polar regions these appearances are sometimes very striking; and the not unfrequent showers of ice crystals at the time, although no palpable cloud is to be seen in the sky, shows what is taking place.

But in whatever part of the sky floating clouds dissolve, whether they are high or low,—whether they vanish as broken cumuli,—as mare's tails, or as mackerel sky,—they leave the aqueous matter of which they were constituted, as transparent vapour in that part of the atmosphere. At great elevations this vapour must be much diffused, or the cold of the part would condense it. A small quantity, however, can exist in the aëriform state at great elevations, and when masses, fleeces, or patches, of cloud, have been dissolved by evaporation in elevated localities, the vapour may possibly remain there for some time. It must, therefore, be frequently found that in such parts,—in a vertical column of the atmosphere, different strata at considerable heights will be more or less highly, though unequally charged with vapour. It is true that as soon as transparent vapour is thus formed, it begins to diffuse itself through the gases that are present, by its expansive force; but the gases in proportion to their density oppose,

temporarily, a certain amount of resistance or impediment to that diffusion, and time is required to overcome this resistance. The vapour may, therefore, for some time exist in the higher regions of the atmosphere in unequal quantities, one part having it nearer to the point of saturation than another at the same height.

It is perhaps necessary here to observe that when evaporation is spoken of by meteorologists, it is almost always that evaporation which takes place from the surface of the globe, that is to say, from either the sea or the land, as it is there that the sun is observed to act, especially when the sky is unclouded. But it is evident that at each hour of the day the solar rays come, from the parts above the atmosphere, with the same power, whether the sky be clouded or clear. If no cloud intervenes, all the rays come to the surface of the earth and heat it, producing, where there is water, a certain amount of evaporation; but if one half or one fourth of them should be intercepted by cloud, only the other half or three-fourths of the rays can affect the surface. It is, however, evident that those rays which are intercepted in the upper regions must strike on the body that intercepts them, and when it is a mass of cloud, the upper surface of the cloud instead of the earth will be acted upon by the rays. Now when the whole sky is covered with dense cloud the greater part of the solar rays will be intercepted by it, and during the day evaporation will be more active at the top of the cloud than on the earth, and aqueous vapour will be sent into the upper air to a greater extent from the former than from the latter. And this evaporation from the cloud must take place however high or low the cloud may be, and the vapour will expand into the adjoining regions with a force and rapidity proportioned to the energy of evaporation. The surface of the cloud will form a kind of base from which the newly formed vapour will spring, and it will pass the most freely in that direction in which it encounters the least resistance. In this way portions of the higher

regions of the atmosphere may be irregularly supplied with vapour for some certain time, and different parts at the same elevation may be unequally saturated with it. In the absence of the sun at night, or even when his power is declining, a reduction of temperature in the locality may condense some of this vapour, and form fresh cloud in a part of the atmosphere that had just before been clear, as the cirrus is often seen to form. It is, however, to be understood that vapour produced from cloud at any height, though it may remain for a time entangled in the gases, will always have a tendency to descend and rest on the earth. It has weight, and notwithstanding its elasticity, must obey the law of gravitation, and descend, however slowly, towards the surface on which it finally has to rest.

Through the operation of the processes that have been pointed out, we have, then, for a time, parts of the higher regions of the atmosphere, at equal altitudes, unequally saturated with vapour: and some of the vapour may, by the disturbances that frequently take place there, be forced up to a still higher region, until it is condensed by greater cold and forms fresh cloud, like the cirrus, at great elevations. Such cloud, however, must be extremely attenuated, and very liable to be again dissolved by evaporation. It must evidently exist in a highly diffused state,—may appear suddenly and pass away in the same manner, every time the cloud is formed the locality becoming warmer, and, as often as evaporation dissolves it, being made cooler.

We may then consider that clouds, from the manner in which they are formed, may be divided into four kinds, each of which may be known from its appearance. First—the Stratus,—which is produced from vapour simply by cold, sometimes very near to the surface of the earth, but often at a considerable height above it, when the particles of water that constitute the cloud either float in the air, or descend so slowly as to appear stationary. And the whole of this cloud

may be, and often is, dissolved by evaporation from its upper part; or if the particles of water should be of unequal size, the larger may descend and impinge upon the smaller, and thus fall by their weight as slight rain. Secondly—the Cumulus. As this cloud is produced through condensation of vapour being so energetic at certain heights in the atmosphere, as to heat the gases and make them ascend, until they expand and cool more vapour, it is to be considered as formed by ascending gases rapidly cooling the vapour that is within them, and often producing much rain. Thirdly—the broken Cumuli—mare's tails and mackerel sky, which are only cumuli undergoing the process of dissipation, by unequal evaporation, on the completion of which process they disappear from view.

These three kinds of cloud are more or less liable to be affected by wind. The stratus is soon swept away by even a moderate wind, and the cumulus, which requires an ascending current in the part, fed from below, to enable it to form, may be disturbed by a curreut above, and may even have its upper portion cut off by evaporation in dry air in the upper regions, into which at the time it may be protruding: whilst the broken cumuli are often carried away to a considerable distance by winds of some briskness. The mare's tails and mackerel sky require slight and unequal movements of the air to produce them, and therefore they cannot exist in strong winds. The fourth kind of clouds—the Cirri—seem to be too lofty to be affected by any movement that takes place near the snrface of the earth.

In addition to these, cloudy masses may be produced by the action of winds. When a current of air is flowing, the friction of the lower part on the surface over which it is passing impedes the progress of that part, whilst the air that is above moves onward freely. The higher and unimpeded air climbs over that which is lower and obstructed, until the former may at last attain a height that will condense some of

the vapour that it contains, and form a broken mass of driving mist or cloud. One current of air may also pass under another and force it up until some of the vapour that is in the upper mass is condensed, but the clouds formed in this way have generally no definite shape, being commonly broken up by the irregular movements of the air.

We have seen that vapour may be taken by warmed air to the higher regions of the atmosphere, and left there in an invisible state; and it is not to be told what is the limit or height to which it may be carried. Cirri have been seen above the height of the lofty tropical mountains, and therefore may be considered to reach say 10,000 yards from the surface of the earth. But at this distance from it the temperature of clear and undisturbed air must be very low, say 100° below that at the surface: and should vapour in some locality be borne to that height, or near to it, and there condensed into cloud, the liquid particles of the cloud would soon be converted into snow. Now both of these processes, of condensation and congelation, heat the gases that are present, and cause them to be forced to a still greater elevation. And it is probable that such processes carry vapour and cloud to the greatest heights at which the cirri have been seen. It is not easy to conceive that any other means exist than those that have been pointed out, to produce cloud at such great elevations. The gases sink 1° in temperature for every 100 yards in height, and they, by their superior cold, condense the greater part of the vapour which they contain, as it rises from the surface, and consequently they prevent much of it from attaining, by its own expansion, so great an elevation as that of which we are speaking. It must, therefore, be carried up by successive condensations and evaporations,—and even to exist there it must be greatly rarefied, and much diffused through the gases. But this diffused vapour could not be condensed into cloud, unless exposed to an intense cold. The precise way in which this can be accomplished may not be

clearly perceived, but it is evident that the first product of condensation, whenever it takes place at such a height, must be quickly converted into snow, though the warmth produced by congelation may be sufficient to float such a cloud of snow to a still higher region.

Both condensation and congelation must, in different latitudes, be frequently carrying vapour into the middle and higher regions of the atmosphere, whilst evaporation of clouds causes them to sink to lower levels, thus producing both ascending and descending masses of air. And a cooled descending mass may force up an adjoining warm and transparent mass, whilst the cold of the elevation may condense some of the vapour that the latter mass contains. These ascents and descents of masses of air may, at any time, produce or dissipate cloud in the higher part of the heavens. A clear part may suddenly become cloudy by the condensation of vapour consequent on a recent elevation, and a cloudy part may be made clear through the superior warmth due to a lower part into which it may have been forced, and these changes may take place when no material disturbance is found in the lower regions. Our knowledge of the derangements that occur in elevated parts, particularly in warm latitudes, is not sufficiently minute to enable us to classify and name the different clouds that are thus produced. They present themselves so suddenly to our view,—intermix and blend together to such various and indefinite extents, and vanish in such different times, as to make it inexpedient, in the present state of our knowledge, to attempt to classify them. At present it may be sufficient to call them by the general name of Cirri, they being presumed to be results of condensation of vapour which had been sent into the higher regions of the atmosphere by cloud evaporation. As our information of what takes place in the higher regions increases, we may possibly become better able to account for the changes that occur there,—to classify the

elevated clouds, and to name them with reference to their origin, or their peculiar states of existence;—but until then it is better to confess our ignorance than to try to subdivide and designate without having a sufficient knowledge of the subject.

We may then consider the stratus to be formed by simple condensation,—the cumulous through the ascent of heated air, and the mare's tails and mackerel sky by unequal cooling of floating clouds,—these designations characterising them when they are distinct, whilst the lofty clouds that appear and disappear in the higher parts of the sky without any apparent cause may be presumed to be the products of vapour that had been previously borne by floating clouds into elevated regions.

ESSAY XIX.

On Climate.

The word "Climate" is used to express the state of a part of the atmospheric space principally in relation to heat and moisture. Thus we say a hot or a cold climate,—a dry or a moist climate;—and this form of expression has important relation not only to man and other animals, but to the whole of the vegetable world which sustains the animals. The term, however, though very useful, and highly expressive, has not a precise and definite meaning, and perhaps the subject does not admit of the use of a word having a limited and well-defined signification. Adopting it therefore in its general and comprehensive sense, it is proposed in this essay to notice some of the varieties of climate that are found in different parts of the world; principally with a view to connect them with their causes.

The unequal influences of the sun on the different parts of *the earth's surface* are undoubtedly the general primary causes of all the differences of climate that are experienced;—but these influences operate in various ways; and if we are to *understand the particular causes that determine the climate of any one* part, we must endeavour to ascertain the form and manner in which the influences act. Solar heat acts directly on different parts of the surface of the globe, but it warms them very unequally, and the warmth thus produced is sometimes carried to other parts by the mechanical agency of air and water,—that is to say, by winds and oceanic currents.

But the same solar heat acts also indirectly in producing climate, through chemical union with water;—and this cause of climate, though felt and popularly acknowledged, has not been explained as fully as the more direct cause. In this Essay it is proposed to advert to various forms and modes in which heat affects and determines climate on the different parts of the surface of the globe, indirectly as well as directly.

When the sun is over the equator, its rays descend there vertically on the surface of the globe, but they deviate from the vertical direction and fall obliquely on parts distant from the equator, and more obliquely in proportion to that distance, until the poles are reached, where the effect produced is the least. More heat is therefore furnished, to a given extent of surface, within the tropics where the sun is vertical, than to any other part, the other parts, north and south, receiving less in proportion to their distances. This, as is well understood, is the first great cause of the different climates that are found in different latitudes.

Where water covers the surface of the globe, as in the great oceans, the surface of that water is level, and the influence of the solar rays on it is strictly according to latitude;—but the land is not level, as some parts of it project much more than others: and this produces, with relation to the sun, difference of aspect. In the part of the world in which we live, it is well known that a southern aspect is warmer than a northern, because the rise of land towards the north presents a face to the sun which then receives more rays than it would have received without that rise. From this cause the southern slopes of the Alps, the Pyrenees, and other mountains in the northern hemisphere, have a climate warmer than the northern slopes. The degree of effect, therefore, produced by the direct action of the solar rays on the different portions of the surface of the earth, although determined principally by latitude, is modified by *the aspect* of the part.

Various other influences are found in operation which further modify these direct causes. In some parts of the world, the surface of the earth, during considerable portions of the year, is screened from the solar rays by a thick covering of clouds which intercepts the heat in its passage to the earth. In the cloudless deserts of Persia, Arabia, and Beloochistan the temperature of the air is raised by the sun to 120° or more, making the climate both hot and dry; whilst in Hindoostan, in a more southern latitude, it seldom rises higher than about 90°, because the latter country is covered by a canopy of clouds, whilst the former countries have clear skies. A great difference of climate, arising from these causes, is found in many parts of the world that are equal in latitude.

Difference of climate, also, arises from difference of the material at the surface on which the sun has to act. Dry land absorbs heat and enables it to accumulate, until the temperature of the ground is raised to a great height. But water does not permit the solar rays so readily to raise its temperature: heat, too, readily enters into chemical union with a part of the water, and when thus united they generally pass away to a distant part in the form of vapour. The temperature of the air over the sea, therefore, does not rise so high as it does frequently over dry land; the climate over the ocean is consequently often found to be cooler than over land in the same latitude, especially when the land is dry:—where it is moist it may approach to the sea climate. In all such cases, however, as those mentioned, the heat that affects the part may be readily seen to be derived directly and immediately from the sun.

But climate is also affected by heat furnished primarily to one part of the globe, and subsequently conveyed to another by the movement of a body receiving it. Thus air that has been heated within or near to the tropics, may pass to higher latitudes, carrying with it its tropical temperature. Or it may pass from a cold to a warm latitude, and take with it

an approximation to the low temperature of the part whence it came. This is familiarly known to us by the way in which north or south winds affect our climate, particularly in the winter, when the northern hemisphere is cold. A body of water, also, which has been warmed in the tropics, may take its heat to a cold latitude, as is the case with the gulf stream that passes along the eastern coast of North America:—or after being exposed to the cold of latitudes far from the tropics, as on the west coast of South America, it may take a low temperature to the equator. These last-named influences, although they probably affect climate less than has been supposed, must undoubtedly produce some effect upon it. These causes of climate, as they operate directly and palpably in the production of their various effects, have been generally recognised, although their different degrees of influence may not have been correctly ascertained.

Another and a very important cause of the different climates that are found in many parts of the world, is the conveyance of latent heat by vapour from the part where evaporation of water takes place, to the part where the heat is set at liberty by the condensation of the vapour. This cause of climate,—if it has not been entirely overlooked, has certainly not had the importance given to it that it deserves. In all parts of the world, particularly those where the atmosphere is dry, heat takes up water from moist surfaces by chemically uniting with it, and the chemical union makes the heat latent and thereby lowers the temperature where that union takes place. This is, no doubt, a cause of the delightful climate that is found on various parts of the tropical oceans, particularly near the commencement of the great tropical trade winds. The atmosphere in those localities being undercharged with moisture, the solar heat that reaches the surface is, to a considerable extent, chemically united with some of the water of the ocean, and the climate is thus rendered cool for the latitude. The same kind of effect is produced by a

dry wind that blows over a country that has been moistened by rain;—and many countries are indebted to the cooling influence of evaporation for the kind of climate they possess. For, evaporation takes place, not only from water and moist ground, but also to a large extent from the surfaces of vegetables; and wherever it occurs, the air is proportionately cooled by it, heat being then absorbed by water and made latent.

But it is from condensation of the vapour thus taken up that the greatest effect is produced on climate by vapour. Evaporation is almost constantly in operation from the whole surface of the ocean, and from a great part of the land, and its cooling effects are therefore extensively, though unequally, diffused. But the vapour that is produced by evaporation is borne largely, and, it may be said, principally, to certain localities of comparatively small extent, and there condensed:—and the heat that had been taken up from very extensive surfaces is given out in these particular localities, and it warms them. Now the heat thus conveyed may be, and frequently is, borne from a warm to a cool latitude, and the locality, which would otherwise have had a cool climate, is thereby made warm.

So far we have spoken of the warmth of the surfaces of the globe, and the part of the atmosphere that is near to it. But the temperature of the atmosphere is influenced by the unequal pressure that exists in it at different heights, temperature diminishing in proportion to the height above the general level of the sea. At a height of 100 yards above that level the air is, on an average, say 1° colder than it is at the surface, in consequence of having to sustain the pressure of a shorter incumbent column of air; and from the same cause it is 1° colder for every additional 100 yards of height. Now air, when charged with vapour, is liable to be mechanically forced to ascend mountains, until it attains a height sufficient to produce a temperature low enough to cause a copious condensation of vapour, a liberation of heat, and a consequent

warming of the locality. The climates of mountainous regions may, therefore, to a considerable extent, be determined by condensation of vapour.

Supposing the air to be saturated, the amount of condensation will depend on the height to which the air is taken, and the climate will be the most altered, from this cause, at considerable heights; yet even at moderate elevations a certain amount of heating may be effected. But whenever condensation of vapour takes place, however near to or far from the surface, the air in the part will be warmed, and the climate proportionately altered by it. Now there are extensive countries where rain falls in great abundance during a considerable part of the year, and where, consequently, much condensation of vapour must have taken place to produce the rain. In latitudes that are generally cool, it is seen that such condensation warms the part, and determines the climate; such are the western parts of Europe, and of North America. In these parts a winter climate, which is warm for the latitude, is evidently produced by condensation of vapour. The air which passes over either the Northern Atlantic, or the Northern Pacific Ocean, takes vapour to the parts named, which is condensed against the elevated lands which are there encountered,—hence the warm winter climates of these countries. Cape Horn,—the western parts of Tierra del Fuego, and many other countries have their winter climates made comparatively warm by the same cause.

The isothermal lines, in the northern hemisphere, as exhibited on Dove's Charts, are very irregular, the freezing points in the winter, of the inland parts of both the old and new Continents, being found below the latitudes of 40°,* whereas, over the Atlantic and Arctic Oceans it is carried so high as about 70° of latitude. And for this extraordinary difference no adequate cause can be discovered, but in the copious condensation of vapour that is known to take place in the latter part. Off Norway, in the latitude of 70°, the average

* See Chart.

temperature of January is only 32°, but in Siberia, in 63 degrees of latitude, it is about 60° colder; the former place being distinguished for the large amount of condensation that takes place at the time, and the latter for its absence.

There is another cause which has a considerable influence on climate. It has been shown that in tropical latitudes, where the sky is clear during the day, the radiated solar rays heat the dry ground until it is raised to a very high temperature. But the sun is not the only body that radiates heat: on the contrary, all bodies radiate it more or less, according to their temperatures; and from dry deserts that have been greatly heated by the sun in the day, heat is freely radiated during the night,—hence in such countries the temperature is high in the day and low in the night. On the 16th June, Burnes says, that "in the desert of Bokhara the thermometer was found to be so high as 103° in the day, whilst it sank to 60° in the night." But in the same latitude, where the sky is covered with thick clouds, there is but little difference between the day and the night temperature. The climates of different parts in the same latitude are therefore, from the different effect of radiation of heat from the earth's surface, materially different. In our own country, we know that a clear sky in the night, particularly in the winter, produces a very different temperature to a cloudy one. When it has been very clear, a thermometer in the air has been found in the night to sink greatly below the day temperature, whilst on a cloudy night but little difference is observed. In certain countries we have respectively, each of these states of the sky permanent for a season, and the consequence is an important modification of the climate from this cause alone.

But when clouds during the day prevent the rays of the sun from reaching the earth, and thus leave the land cooler than it would be if exposed to their full influence, we are not to suppose that these rays produce no effect. Those which do not reach the earth act upon the upper surface of the cloud,

and vaporise some of its particles. Evaporation at the upper surface of the cloud produces just the same kind of effect that it does at the surface of the earth. In converting the particles of liquid water into vapour it absorbs the solar heat, which heat remains in the vapour in a latent state, ready to be liberated whenever condensation may occur: this may be in the same locality, or it may be in any distant part to which wind may convey the vapour.

It has been already shewn that the slope or aspect of land has an influence on climate;—and also that the temperature of air is affected by the reduced incumbent pressure to which it is subjected at certain heights. But there are certain places among mountains which have particular climates, apparently not to be accounted for from the operation of either of those causes, nor from both combined together. In Switzerland, particularly in the Valais during the summer, heat acts as powerfully on vegetation as it does in warmer latitudes with lower levels It may indeed be supposed, that in that narrow valley, the heat is reflected from rocks on the one side to rocks on the other, and is thus accumulated, until the temperature is varied to the great height which it afterwards attains. Admitting this, the warm summer climate of the Valais may be attributed to aspect. But among the Himalaya Mountains we are told that there are broad vallies,—almost plains,—at an elevation that should make them very cold, from their height alone,—that in fact should, from their elevation, leave them in a freezing state: yet at these heights the climate is sufficiently warm in the summer to ripen grain. And it appears also, that this warm summer climate cannot in certain parts be attributed to copious condensation of vapour, as lofty intervening mountains prevent much vapour arriving there from lower levels. Now to what cause can we attribute the superior warmth found here? The facts which are now in course of being furnished respecting this part of the world, will probably show the danger of premature generalisations,

and the necessity of receiving with caution any theory that may have been adopted from the evidence of partial facts.

Meteorologists say, that at the sea level, where the pressure of the atmosphere is equal to nearly 30 inches of mercury, its general temperature at the surface is about 80° at the equator, becoming less towards the polar regions; and, that this temperature diminishes on an average in the upper parts of the atmosphere, through reduction of incumbent pressure, 1° for every 100 yards of height. From this, it would follow, that even at the equator, at the height of 4,800 yards, in an atmosphere undisturbed by condensation of vapour, the temperature cannot be higher than 32°—the freezing point. But this we are told by travellers is greatly at variance with ascertained facts, and we have to find out the cause of these extraordinary facts.

It is considered to be proved that over the sea where the temperature is 80°, in a vertical column of an undisturbed atmosphere, the freezing point will be reached at a height of 4,800 yards. But are we therefore at liberty to conclude that the air over land, which land is itself 4,800 yards high, must be as cold as the air over the sea at the same height? The temperature of 80° is found in air over the sea near the surface, because the sun acts on the surface of the sea with sufficient force to raise the temperature of the air to that height. But the sun may be equally capable of heating the surface of land which is 4,800 yards high. All that appears necessary to produce such a heating is, that a broad surface of the land should be presented to the solar rays with a suitable aspect. For it is to be observed, that it is principally the surface of the globe that is heated by the sun, and that heat, whatever may be its degree, is communicated from the surface to the atmosphere which rests upon it. But there is no reason that the lower part of an atmosphere, if the land on which it rests is exposed to the full influence of the solar rays equal to only 15 inches of mercury, should not be heated as high as one equal in weight to 30 inches. Both airs might

be in contact with matter which may be raised to the same temperature, and might be equally well heated.

But would the lighter and warmer air, at a height of 4,800 yards, when so heated in a particular part, remain within the locality? or would it rapidly change places with the colder air over the sea that was at the same elevation as itself? This, it appears, would to a certain extent depend on local peculiarities of the part. Were the elevated land a cone, the air around the cone, as it became heated, would no doubt be freely pressed up by the colder air that existed at a distance at the same level, and in this way the land would be presented with continued supplies of cold air, to be successively heated, which would prevent any portion of it from being raised to the high temperature of 80°, or probably to any temperature near to that degree. But suppose the elevated land to be an extensive plain, or, if necessary, a valley or basin, and then it will be perceived that the distant cool air, at the same height, could not, with equal facility, force up the warm air from the interior of this basin, and take its place. So much time might be required to effect the substitution of the cool for the warm air, as to enable the central portion of the elevated land to heat the mass of air which rested on it to a temperature approximating to that of the land itself. Now may not the elevated land alluded to among the Himalaya Mountains be similarly circumstanced to that which has been imagined? It appears to be a kind of table land, or flat valley, almost surrounded by mountains, where the sun, when nearly vertical, acts with much power on the ground, and greatly heats both it and the air resting upon it. And the heated air being protected by intervening ridges of mountains, from the action of cold air at a distance, may be raised to a temperature sufficiently high to give a very warm climate to the part, considering its latitude and elevation. There may be, and probably are, many other parts of the world affected by similar circumstances, to a less or greater extent, that have their climates modified accordingly.

ESSAY XX.

On Daily Changes of Electric Tension in the Atmosphere.

In the volume of the British Association for the Advancement of Science for the year 1849, there is a Report by Mr. W. R. Birt, "On the Discussion of the Electrical Observations made at Kew in the years 1845, 1846, and 1847, including others on the same subject made at Greenwich;" and, from the way in which the Report is given to the world, it may be taken as an authorised discussion of the observations made at those public establishments for the period named, having a certain amount of official sanction. Viewed in this way, the Report has greater importance than would be attached to it as the production of an individual, and more particularly requires an examination of any errors or defects that may be found to pervade it.

Throughout the whole of the laborious investigation of Mr. Birt, it appears to be assumed that the air has some amount of electrical tension, the force of which varies from time to time in an irregular way; and the object of the inquirer is to ascertain what is the cause of this variation. It is also assumed that separate electric tension of aqueous vapour modifies that of the air; and, in the latter part, cloud and rain are supposed to furnish other tensions which may modify the rest, and contribute towards the general results as found in the registrations. But in the whole of the examinations and discussions, no notice is taken of the great disturbances that are caused in the atmosphere by the processes of

evaporation of water and condensation of vapour. The observations were in all 10,526 during the three years, of which 10,176 were positive, and 324 negative, in addition to 26 not embraced in the discussion.

The writer does not profess to have arrived at any conclusions respecting the causes of the changes in the electric tension of the atmosphere, although he directs attention to what he supposes may be the causes. He particularly examines the daily changes which are stated to "depend on, or are connected with the rotation of the earth on its axis." This seems to point at some general influence, rather than to a disturbance arising from causes which have a local origin, and a limited range of operation for the time.

The diurnal observations were made with Henley's electrometer, and were twelve in number, made at the even hours, as given in the following table, which exhibits the times of observation, the number made in each period, and the mean two-hourly tensions found for the whole three years:—

Hours......	12 p m.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 a.m.	2 p.m.	4 p.m.	6 p.m.	8 p.m.	10 p.m.
Number...	655	748	804	566	1,047	1,013	848	858	878	874	878	1,007
Tension ...	22.6	20.1	20.5	34.2	68.2	88.1	75.4	71.5	69.1	84.8	102.4	104*

It will be observed from this table, that from 4 A.M. the commencement of the meteorological day, the electric tension rises from 20.5, until, at 10 A.M., it reaches 88.1. It then begins to fall, and continues falling until four in the afternoon, by which time it declines to 69.1. From four in the afternoon it commences a second rise, and by ten at night reaches the great height of 104. A second fall now begins, and the descent to midnight is very abrupt, as it goes down to 22.6, and at four in the morning is again at 20.5. This table shows the mean diurnal fluctuations of the electric tension for three years; but there is a considerable difference in it in winter, as compared with summer; this however need not be adverted to at present.

* See diagram of electric tension at the bottom of Plate 4.

The observations are then separated by Mr. Birt into two classes; one including those made in serene weather, when the tension was low, and the other including the high tensions, 80 being the dividing point. Monthly, and other tensions, are also given and discussed, the object being to classify the observations in various ways, in order, if possible, to find out the cause of the fluctuation of the tension. But it will be enough for us at present to observe the table which exhibits the means of the three years.

The writer of the Report endeavours to show that there is a connection between electric tension and temperature; but although he traces occasional approximations, he confesses that the two do not march harmoniously together; and he therefore considers the facts as failing to furnish evidence of the two having the relation of cause and effect. Admitting this, however, there may still be a connection between the changes that take place in the amounts of caloric matter and of electric tension.

The daily change of temperature which ordinarily takes place in the air near the surface of the earth, may be seen in a curve, which is taken from the Makerstoun observations,* containing one rise from 4 A.M. up to about 1 P.M., and one fall from that time to the next, 4 A.M.; whilst the curve of electric tension formed from the table that has been given, shows a double fluctuation, having two risings and two fallings in the twenty-four hours; in this peculiarity resembling the daily fluctuations of the barometer. The last-named instrument measuring atmospheric pressure, as shown in another typical curve, rises from four until ten in the morning, during which time electric tension also rises; leaving us at liberty to suppose that both are in some way influenced by a common cause: at the same period temperature also rises, as may be seen in the curve showing the daily movement of temperature. But it will be perceived that after ten o'clock in the day,

* See Plate 4.

temperature continues to rise till one o'clock, whilst the barometer and electric tension both decline. Temperature now ceases to move with electric tension and atmospheric pressure, and marches in the opposite direction. From one o'clock till four in the afternoon, all the three curves move together and decline; but at four, whilst temperature continues to fall, both atmospheric pressure and electric tension begin to rise; again showing, that whilst temperature continues to move in the same direction, electric tension and atmospheric pressure reverse their movements. And the curve of temperature continues to decline until ten at night, during which time the other two curves rise. It appears, therefore, we have no reason to suppose that temperature near the surface of the earth is the cause of the alteration that takes place in electric tension, as the two sometimes move together, and at other times in opposite directions. But are we, from this fact, at liberty to conclude that no connection exists between heat and electricity?

Before attempting to answer this question, it is desirable that some changes should be noticed that are known to take place during the two-hourly periods under consideration. When the rising sun, by furnishing additional heat, gives increased energy to evaporation of water, more aqueous vapour is produced near the surface of the earth; and the heat required to convert water into vapour is thereby changed from an active to a latent state, whilst the tension of electricity increases. Now, if we can for a moment suppose that the absorption of heat by vapour at the time of its formation, is accompanied by a liberation of electricity from the water that was converted into vapour, it may account for the increase of electric tension that then takes place. But this increase would be, not a consequence of the rise of temperature which occurred at the same time, but a result of the chemical change that had been effected in the state of the water when it was converted from a liquid to an aëriform substance.

Evaporation of water from the surface of the earth increases up to ten o'clock in the morning; and we have seen that electric tension also increases during the same time, apparently as a consequence of the conversion of water into vapour; but after ten, though evaporation from the surface continues and further increases, electric tension not only ceases to increase, but declines. Now what can be the cause of this decline, while both evaporation and temperature are on the increase?

Up to ten o'clock we have supposed that the vapour which was raised from the surface of the earth, in its formation absorbed heat, and also discharged into the atmosphere a certain amount of electricity, which was seen in the increased tension of that substance. But at ten, the vapour which had been evaporated from the surface is, to a considerable extent, known to be condensed in the upper part of the atmosphere; this process continuing in that part until four o'clock in the afternoon. And as we suppose that evaporation may have liberated electricity and increased electric tension in the morning, so condensation must be presumed to absorb electricity and reduce its tension in the day. The conclusion, then, that we arrive at is, that a chemical change takes place when the solar heat in the morning converts water into vapour, which sets electricity free and increases its tension in the open atmospheric space; and that another chemical change of an opposite character occurs at and after ten in the morning, when that vapour is condensed in the high and cold regions of the air; and this latter change absorbs electricity and reduces its tension. The movements of atmospheric pressure accord with this view of what takes place after ten in the morning; the diminution of pressure that then begins, being a consequence of the liberated heat raising the temperature of the atmospheric column. Thus we see, that heat or caloric may be looked upon as the prime active cause both of the fluctuation of atmospheric pressure and of electric tension, the sun being the source from whence that heat is derived.

From four in the afternoon until ten at night, is a very interesting period in relation to the subject of our inquiry. During this time, electric tension increases and the barometer rises; the two now move together in their rise, as they had done just before in their fall; leaving us at liberty to conclude that they may have been affected by a common cause. And as we presumed that evaporation from the surface of the earth may have set electricity free in the morning, from four to ten, and increased its tension, so from four to ten in the evening, as the same process of evaporation is known to be taking place in the higher regions of the atmosphere, the same results are found: as evaporation of cloud proceeds, heat is absorbed by vapour and made latent in the locality; electricity is set free, and its tension increased. It is unnecessary here to give further evidence of this process, as it has been sufficiently shown that cloud is formed by condensation in the middle of the day, and dissolved by evaporation in the afternoon, between four and ten; and we may infer that the cloud formation in some way reduced electric tension, and the dissolution of the cloud by evaporation increased it.

At ten o'clock at night, the evening increase of electricity has reached its highest point, and it is at this time that the globules of water that had been left floating in the air in the form of cloud, from four o'clock, had been fully converted into invisible vapour, and had taken up a large amount of heat and made it latent. This is shown to have occurred by the cooling of the air and the increase of atmospheric pressure up to ten o'clock, both of these moving in harmony with the alteration of electric tension. But all these facts, while they indicate that heat and electricity act and re-act on each other, do not countenance the idea that temperature moves in accordance with electric tension. The temperature of the air that is measured by a thermometer is produced by an accumulation of free heat, which has comparatively little effect in disturbing the electrical equilibrium. We are not,

however, at liberty to suppose that even this movement of heat has no effect on electricity, the probability being that these two imponderable substances always display their antagonism to some extent, and act and re-act on each other. But it is only when accumulated in large quantities, as in streams of lightning, or when energetic chemical changes are taking place in other bodies, that they violently disturb each other.

The facts that have been stated furnish reason to infer that the diurnal fluctuations of electric tension in our atmosphere are results, not of simple changes of temperature, nor of the presence of less or more vapour, nor of clouds, rain, or hail, as such, but of the diurnal alterations that take place in the electric state of the chemical substance water, caused by solar heat vaporising the liquid in the morning; then by the cold air in the higher part of the atmosphere condensing the vapour, and forming globules of water from ten in the morning till four in the afternoon; and afterwards by those globules of water being again changed into vapour from four in the afternoon until ten at night, when cloud is dissolved by evaporation. These three separate processes, it is conceived, account for the three movements of electric tension which occur from four in the morning until ten at night, at which hour the liberated electricity shows a high tension. After this time, solar influence being absent, electricity seems to diffuse itself rapidly, and establishes a new equilibrium in accordance with the colder state of the atmosphere.

It is not, however, here maintained that the view exhibited of the causes of the fluctuations of electric tension is proved to be correct; but it presents known facts so much in harmony with each other, and with the hypothesis suggested, as to make it desirable that in future investigations and discussions of the subject, care should be taken to ascertain whether the facts which are observed accord with the hypothesis.

ESSAY XXI.

On Researches in Meteorology.

A trade wind, such as is found to blow over the ocean in many parts of the world, may in some respects be compared with a river which has its origin on high land, its course through a low country, and its termination in the ocean. The wind is found to commence in a certain locality, probably descending from higher regions like a mountain spring, not, however, fixed to a particular place like the spring, but changing according to the movement of the sun, the great, though frequently the remote cause of all movements of the air. The wind then proceeds along a kind of channel in the atmosphere towards the place of its termination, and throughout its course is more or less exposed to observation and examination by the meteorological inquirer. There is reason to believe that in the commencement of the course it will, on due inquiry, be found charged with only a moderate portion of that important constituent of the atmosphere, aqueous vapour, and will therefore be dry,—or the dew-point within it will be considerably below the temperature. But as it proceeds forward, passing over the surface of the ocean, it will take up an additional supply of vapour from the water, until it approaches the point of saturation; and an examination of the wind in the different parts of its course will enable us to ascertain how much vapour has been taken up in its passage, as well as the part from which it was obtained.

But if the wind proceeds from a cool to a warm latitude, the difference between the dew-point and the temperature, instead of decreasing may increase,—through a rise of the temperature which will more than counterbalance the supply

of vapour that has been received during the time; and the extent of this increase of dryness will depend on the rapidity with which the aërial current flows. The north-east trade wind of the Atlantic Ocean, one of the great trade winds, may be described as starting from the Canary Islands, and in that locality it is a dry wind: the difference between the temperature and the dew-point being there found to be frequently from 15 to 20 degrees. Colonel Sabine ascertained that when the wind came from the land in this part the dew-point was 37.5°, whilst the temperature of the air was 66°, making a difference of 28.5° between the dew-point and the temperature. And Humboldt discovered that the thermometer rose from 64°, the height at which it stood at Teneriffe, to 77° at Cumana;—and as the dew-point at the latter place is frequently above 70°, and in the neighbourhood often approaches 80°—evaporation from the surface of the ocean must, we presume, send vapour enough into the atmosphere to raise the dew-point say about 20°. Now a proper registration of the dew-point, or, as attended with less trouble, of the wet and the dry bulb thermometers, along the line of this wind between the two places, would present to our view important evidence of the supply of vapour that is furnished by the water of the ocean, and which is borne by the trade wind to the area of its condensation, the elevated land of America.

In like manner, the hygrometrical state of the air might be registered in the south-east wind of the Southern Atlantic Ocean at its commencement near the Cape of Good Hope, tracing it as it proceeds westward in its course towards the coast of South America, near to which, the 10th degree of south latitude, is said to be the heart of this trade wind.*

* Of this wind the Rev. H. Malcolm says, in his *Voyages*,—"On leaving the Cape of Good Hope, a delightful breeze from the south-east brought us at once into the regular trade wind, so that we scarcely started tack or sheet till off St. Helena, on the 31st January. Squalls and calms produced by the proximity of this lofty island, kept us near it for twenty-four hours. Heavy clouds lowered on the summits of its mountains."—P. 201.

Such a registration would show the increase of atmospheric vapour along the line of this wind, and would point out the quantity of it furnished to the large area over the land which extends from the Brazilian coast to the Cordilleras of the Andes, to be there condensed into rain. These two atmospheric currents furnish the material which, when condensed by cold, supplies the immense bodies of water that flow down the Orinoco, the Amazon, and the Plate rivers. And while collecting these facts, other meteorological observations might be made and recorded, particularly those having reference to the hygrometrical state of the air, to as great heights as should be found practicable.*

In the commencing part of the course of the dry winds that have been named, few or no clouds are to be seen, but afterwards they appear, and the place of their first appearance should be noted, as well as of the changes in the appearances which follow,—including the forms, density, and elevation of the clouds;—the objects being to ascertain, first, to what height the vapour extends by its own expansion, and secondly, that to which it is subsequently carried through condensation warming the gases in the locality. And these observations should be continued after the wind has passed from the sea to the land, and the character of the clouds should be noticed in connection with the form and elevation of the land:—and lastly, the quantity of rain that falls in different localities should be registered, distinguishing the falls on low from those on high lands. If this were accomplished between the coast and the higher parts of the mountains, a meteorological chart of the locality might be constructed which would exhibit a considerable amount of evidence respecting the processes that are taking place over the land, whilst the previous registrations over the

* In the Chart (see Plate 5) a number of arrows are shown over the ocean, intended to indicate the prevailing winds in the respective localities. The whole of them present a general view of the principal continuous winds that are found on the surface of the globe;—they, however, point out the direction in which their termini may be discovered, rather than the localities in which they commence.

sea would show, to some extent, what was occurring in that portion of the atmosphere which was passing over the ocean. Such a chart would enable us to discover where the vapour arose,—how it accumulated and ascended in the atmosphere,—what appearance it presented there in the shape of clouds, to indicate the changes that were occurring in the upper regions,—its horizontal progress over both the water and the land,—and finally, the locality in which it was condensed and fell as rain.

This information it is desirable that we should possess, as there is reason to believe that where the sun acts with great power on the surface of the ocean, the vapour which is there raised by evaporation first expands by its own elastic force into the atmosphere, where, at a moderate height, the cold of the gases condenses some of it. This condensation warms the gases, and they consequently ascend, taking with them the vapour that remains in an uncondensed form to a higher region. A fresh supply of vapour from below then goes through the same process, forcing up the first, and thus a still higher region is reached;—and the gases in the part, by these successive operations, have their temperature raised above that which belongs to their latitude and elevation. This warming process enables the gases that are in motion as a wind, to bear along with them in their course through the higher parts of the atmospheric space, not only masses of cloud, but larger quantities of vapour than they could otherwise contain in an aëriform state, and to convey it to the distant mountains where it is finally condensed.

In the great Pacific Ocean, winds are found similar to those that have been noticed in the Atlantic, and these winds should, if possible, be subjected to similar meteorological examinations. They constitute the north-east and south-east trade winds of the Pacific, near to and within the tropics, and they blow over the eastern side of that immense ocean—becoming more decidedly east winds as they approach the equator, and at last

proceeding as such, to that extensive region of condensation, the great East Indian Archipelago. Malte Brun says—"The tropical trade winds of the Pacific are feeble and circumscribed on the coast of America, where they only begin near or even within the tropics. On the opposite coasts of Asia, and the regions to the south, they extend as far as the 40th parallel."* The parts of these winds that are the most distant from the region of condensation, and particularly those that are passing from colder to warmer latitudes, will no doubt be found dry, that is, the dew-point in them will be considerably below the temperature. But where they proceed rapidly towards the equator, this dryness may possibly be increased by the higher temperature to which they are raised in a warmer latitude. The sky in these parts will therefore be clear, and the air undisturbed except by its regular movement towards the Archipelago. It is of these parts that navigators speak with so much satisfaction, when describing the clear atmosphere and delightful breezes of this ocean.

One writer says, from about 110° west longitude, "the light trade winds were sweeping up towards the islands, (the Marquesas,) all that we had to do was to square the yards and keep the vessel before the breeze." "The sky presented a clear expanse of the most delicate blue, except along the skirts of the horizon, where you might see a thin drapery of pale clouds which never varied their form or colour. But the most impressive feature of the scene was the almost unbroken silence that reigned over sky and water."†

These north-east and south-east winds, like the trades of the Atlantic, alter to a certain extent with the passage of the sun across the tropics, being stronger in the southern hemisphere when the sun is south of the equator, and in the northern hemisphere when he is north of it; that is, the winds are stronger in the hemisphere which is, at the time, the most fully charged with vapour.

* Malte Brun, vol. i., p. 390.

† Melville's "Marquesas Islands," p. 8.

Near to the equator, and to the American coast in this ocean, there is a region of calm, apparently produced by the adjoining mountains presenting an obstruction to the air passing from the east. But the perennial wind that comes from the south, and passes along the coasts of Chili and Peru, as far as the Galapagos Islands, there turns across the ocean, proceeds westward, and constitutes a part of the great trade wind.*

But these winds, blowing so moderately and steadily, through bright skies, in the eastern part of the Pacific, as they cross the great ocean towards the west, take up vapour freely, and are altered in their character;—and a regular registration of the dew-point, or of the wet bulb thermometer, with the temperature, would enable us to trace where the vapour was taken up, and to what extent it was accumulated. As the winds reach the western parts of this ocean, all accounts agree that they lose the mild character they have in the east. The skies become cloudy, and the winds more violent and irregular, until, on reaching the numerous small islands that lie in front of the Eastern Archipelago, stormy weather is frequently encountered, and when the Archipelago itself is reached, the storms assume a character of fierceness. And a proper hygrometrical registration near the surface, would doubtless exhibit to view the proportional amounts of vapour that are in the lower regions of the air over the whole of the ocean.

But we know very little of the changes that take place in the higher regions; efforts should therefore be made to increase our knowledge of those regions.† From the known

* See page 21.

† Lunardi (the aëronaut) on one occasion travelled at the rate of seventy miles an hour in his balloon, while at Edinburgh, where he ascended, the air was quite tranquil: and many other aëronauts have found strong winds blowing in the higher regions when it was calm below, or the wind above was blowing in a different direction to that below; but no effort has been made to trace the causes of such diversities of wind at different elevations.

action of the gases in condensing vapour, and then of the vapour in heating the gases and causing them to rise in the part, we may, however, venture to infer, that when clouds form rapidly in the sky, much disturbance will take place in the atmosphere, which disturbance will carry considerable quantities of vapour into the higher regions; hence the necessity of observing the commencement and continuation of the clouding of the sky, and the character of the clouds in the different parts.

There is another reason that the hygrometrical state of the air which passes over this ocean should be observed. It is well known that winds are more or less disturbed in their courses by the presence, or even by the neighbourhood of islands, and as we are presuming that the great general disturbing cause is to be found in the vapour which the air contains, it is desirable that we should know what quantity it holds in parts at different distances from the islands; and observation might show whether the air was less saturated near to, than at a distance from them. There is now so much communication between the western coast of America and the eastern side of Australasia, that we may indulge in the hope that such meteorological facts will be furnished as will throw new light on this subject.

It is common for writers to say that the atmosphere was, at a particular period, clear, *on account of the large quantity of vapour that was dissolved in it*;—this contains an error. It does not appear that the gases are more transparent when vapour is present than when it is absent;—nor is there any reason to presume that vapour is more transparent than the gases. There is no doubt that the atmospherie space is more clear at some times than at others; but this clearness may be considered to arise from the absence of all opaque matter at the time.

A very transparent atmosphere is generally found both before and after showers of rain. After a heavy shower

objects may be seen with great distinctness: but this is evidently not attributable to an abundance of vapour, as the rain must have reduced the quantity in the atmosphere. The cause of the clearness of the air under such circumstances is probably to be found in the action of the drops of water, as they fall to the earth, on small floating bodies. Over land fine dust is generally floating in the air, as may be seen when solar light is admitted to a dark room through a small aperture, and ascending vapour is liable to be condensed by cold into small globules of water: now drops of rain will impinge upon and carry down all these particles, and the air may be thus cleared of all such bodies. But the same clearness is observable before rain. This is, however, when cloud formation produces an ascending current of air which carries up all floating substances to the part where condensation is taking place; leaving the air free from them.*

In what has been said in this Essay, no allusion has been made to barometrical registrations, but it is obvious that they should be made in connection with the others. Reasons have been already given for believing that fluctuations of atmospheric pressure arise from partial heating of the gases by condensation of vapour. If this is correct, the gaseous pressure will be at its full average only where no condensation is taking place, and will fall below it as condensation increases; and, all other circumstances being the same, it will be the least where the amount of condensation is the greatest in a given time. Now a run by a ship from a region of clear skies, undisturbed except by the regular trade wind, in the eastern part of the Pacific, to the clouded and stormy western parts, would be likely to furnish the means of ascertaining how far atmospheric pressure is affected from this source. It is probably true that the barometer will be differently affected by condensation, according as it takes place near to the level of the sea, or at a considerable height above it; and this may

* See page 151.

render a full inquiry very difficult, but if, as is presumed to be the fact, the barometer generally stands higher in a clear, and lower in a cloudy atmosphere, and lowest in the most cloudy, it may be taken as good evidence that the mercury sinks in consequence of condensation of vapour having made the atmosphere lighter, as well as more cloudy. There are many parts, particularly on sea coasts, where the barometer rises every morning from four to ten o'clock, and sinks from the latter hour until four in the afternoon, from which time it again rises until ten at night,—sinking afterwards till four o'clock in the morning. The causes of this regular daily fluctuation I have explained elsewhere, and if that explanation is correct, this kind of fluctuation will be very small in a clear oceanic atmosphere, but will become greater when there are cloudy days and clear nights; and it will disappear when both day and night are much but equally clouded, because the periodicity of the daily solar action on the surface will be then destroyed. A careful hourly or two-hourly registration of the barometer on board a ship, through the whole courses of the trade winds of the Atlantic and Pacific Oceans, would be almost certain to throw much light on the causes of the daily, as well as of the irregular, fluctuations of atmospheric pressure.

All that has been said respecting the trade winds of the Atlantic and Pacific, will apply more or less to the Monsoons of the Indian Ocean. These are indeed trade winds, which differ from those already named only because they are more affected by the passage of the sun from one tropic to the other. The north wind of the Arabian Sea, which becomes the north-west wind of the Indian Ocean, has its origin, apparently, in so remote a part as Siberia. It passes over central Asia, the desert of Bokhara, Persia, and Arabia, as a very dry wind, but in crossing the Northern Indian Ocean, near the equator, to go to the great Indian Archipelago, the place of its termination, it evidently takes up much vapour.

Now an examination of the hygrometrical state of this wind throughout its course, at the surface of the earth, as well as to as great heights as is practicable, and its pressure on the barometer, would doubtless exhibit interesting results. From what we already know, it is not too much to say that such examination would furnish facts which would materially assist to explain the pressures that are taking place in the atmosphere much more clearly than can be done at present. The gradual though probably irregular rise of the dew-point over this extensive range, would point out the great source of atmospheric disturbance. Another wind which in the winter blows over China as a very dry one, passes on to the Eastern Archipelago, where it becomes wet, and furnishes much rain—this, if examined, would no doubt furnish similar facts to that just treated of.

The northern wind of the Indian Ocean resembles the winds of the Atlantic and Pacific Oceans, inasmuch as, like them, it has its origin and termination in the same hemisphere. But there is another wind that prevails in the Indian Ocean which differs from those that have been named, in the circumstance of having its origin in one hemisphere and its termination in the other:—this is the south-west Monsoon of the Indian Ocean. It is found blowing mildly in the narrow sea between Madagascar and Africa, and though that is in a warm latitude, where evaporation must be active, yet, from the state of the sky, it may with propriety be called a dry wind. Its dryness, however, will probably be found to arise rather from high temperature than a low dew-point. Observers of this locality speak of the season of the south-west Monsoon as being the fine season of the part, and it is evidently rendered such by that Monsoon taking the vapour, which has been produced there by evaporation, towards the north, in which direction the wind proceeds,—crossing the equator—entering the northern hemisphere, and passing over the whole Indian Ocean, taking up additional vapour as it proceeds to its area of condensation,

the Himalaya and other mountains of Hindoostan. A careful hygrometrical examination of this wind, blowing throughout its course in such warm latitudes as it does, would no doubt show that it becomes more moist as it passes over the tropical seas, and that it finally takes with it that large amount of vapour which, when converted into rain, deluges Hindoostan and adjoining countries. As this wind comes from the west, as well as from the south,—the western sides generally of the countries named are, in the south-west Monsoon, very rainy. But there is an exception to this which is worth noticing, as it affords an opportunity for explaining an apparent anomaly, and really shows how the atmospheric disturbances are produced.

Near the mouth of the river Indus, and over the low country of Cutch, from the 23rd to the 25th degree of north latitude, the south-west Monsoon is a dry wind. Mrs. Postans says, in her book on Cutch, that "the south-western Monsoon is usually slight. The prevailing winds are from the west to south-west, and the latter, contrary to the general experience of other parts on this side of India, are in this province preventive of rain. When these winds blow frequently during the Monsoon months of July, August, and September, they are always observed to cause drought."* This statement appears to be at variance with what has been here advanced. But let us consider what are the general atmospheric movements and processes that are known to be going on in these parts at the time. Extremely copious condensation of aqueous vapour, brought from the wide expanse of the tropical Indian Ocean, is taking place, particularly against the south-west sides of the Himalaya Mountains, where, as a necessary consequence of that condensation, a considerable vacuum must be created in the atmosphere. Into this vacuum the air,—not only from the Indian Ocean, but also from any other neighbouring part, will be disposed to rush with a force

* See page 317.

proportioned to the degree of vacuum that exists. Masses of air would, no doubt, press into the vacuum directly from the north and east, were they not prevented by lofty mountains. But beyond these mountains winds are found, and one may be traced passing round them to the west over Persia and Arabia, and, after crossing the Persian Gulf and a part of the Arabian Sea, it blows across the lower Indus and Cutch, towards the vacuum that exists near the south side of the Himalaya Mountains. The very rainy winds of Hindoostan come from the southern and western parts of the broad Indian Ocean, and supply the vapour that is condensed, yet the vacuum that is thereby created permits the dry winds of Persia and Arabia also to pass towards it over Cutch; and an examination of the state of the air in the various winds that rush from different quarters towards the line of condensation in this part, would show, not only whence the vapour came, but also whence came the comparatively dry wind that is found near the part.

At Bombay and other places on the south-western coast of India, the air, during the summer Monsoon, is extremely moist; whilst it is comparatively dry in the winter Monsoon, and it is considered by many persons strange, that there should be, as there undoubtedly is, a considerable daily change of atmospheric pressure in the latter season, whilst there is scarcely any in the former. It has been said—if all the great disturbances of the atmosphere arise from condensation of vapour, what can cause this daily change of pressure in the dry season, when there is but little vapour in the air, whilst there is no such change in the wet season, when there is much? The answer to this is, that the daily change of the pressure of the atmosphere, is a consequence of the sky being in a different state, during the day, to what it is in the night, during the dry season. In this season the sun, shining through a clear sky, heats the surface of the earth in the morning and greatly raises the temperature;—this increases

evaporation of water from both sea and land, and vapour passes freely into the air, augmenting the general pressure of the atmosphere, and causing the barometer to rise, until the sun has attained a certain height in the heavens, say at about nine or ten o'clock. After this evaporation becomes more energetic, more vapour is sent into the atmosphere, where, by its elastic force, it ascends, penetrating the gases that exist there. But these gases are colder than the vapour, and some of the latter is soon condensed into mist, which may be readily seen, as it dims the light of the sun. That sun, however, now shining partly on the mist instead of wholly on the earth—probably re-evaporates it, and the newly produced vapour ascends to a greater height, to undergo again the same kind of condensation. These processes being continued and the air filled with mist, and warmed by condensation, has its weight reduced and the barometer falls, though possibly no thick cloud may have appeared in the sky;—the conversion of the transparent vapour into mist being only just sufficient to warm and lighten the atmosphere for the time. When the heat of the sun declines, this mist is left in the air, and in due time is converted again into transparent vapour by evaporation, thus cooling the air, making it heavier, and causing the barometer to rise, as it does from about four to ten o'clock. It is thus seen that the daily fluctuation of atmospheric pressure at Bombay, in the dry season, is a result of the unequal influence of the sun during the different periods of the day. And if suitable observations were made there of the hygrometrical state of the air during those periods, and the degrees of mistiness or clouding of the sky noted, we should probably have evidence of the causes of daily fluctuations of atmospheric pressure.

In the summer Monsoon very little daily change of pressure is experienced, because a great amount of condensation is unceasingly taking place among the mountains, causing the air to rush from the sea to the mountains with nearly equal force,

by night and by day, and covering the sky at all hours with thick clouds. The sun, therefore, has not much more effect on the surface of the land during the day than it has at night; there is, consequently, no unequal daily heating of the air, and the barometer remains undisturbed by any regularly changing daily influence.*

It must then, we presume, be admitted to be highly desirable that meteorological observations should be made in such a way, and on such a plan, as will best exhibit the action of aqueous vapour in producing atmospheric disturbances. There are many observatories and still more numerous observers in various parts of the world, but the latter do not appear to act on a good system;—they seem to have no definite object in view, and therefore observe every fact as far as they can, appearing to consider all observations of equal importance. The result is, that we have accumulated, in works on Meteorology, an immense number of facts, elaborately corrected, and formidable in their appearance to the student who ventures to encounter them, without having that information furnished which is really wanted. The British and American Governments have recently directed navigators of their respective countries to observe and register the winds that are found over all parts of the ocean, and it is said that considerable benefit has already resulted from information thus collected, in finding better courses for ships to pursue in their voyages.

* In the volume of the British Association for 1851, there is a communication from Dr. Buist, on the change from the winter to the summer Monsoon, in which he says, that at Bombay, "about the beginning of May, the air becomes damp and muggy, the land and sea breezes become irregular, and a calm prevails over a great part of the night, with the thermometer from 80° to 85°, the air being surcharged with moisture. About the middle of the month, long banks of electric clouds make their appearance over the mountains in the east. Towards the end of the month, sheet lightning appears from these clouds, and in time the Monsoon opens from them. These masses are frequently magnificent at sunset, but they seldom appear before mid-day, and are rarely visible long after sunset.—P. 144.

But such information, although very valuable, gives only the naked facts, showing that particular winds have been found in certain parts at certain seasons. But if we understood the nature and operations of the disturbing causes which produce the winds, we should be better able to account for the embarrassing anomalies that are so often met with, and navigators might be better able to act when they occur, than they can from the use of mere empirical knowledge, however much of it may be possessed. But apart from the practical benefits which may reasonably be expected to result from the inquiries here recommended, it is desirable that they should be pursued in order to increase our knowledge of what is taking place in that great aërial ocean within which we live and move, and by whose changes and disturbances we are so variously and extensively affected.

ESSAY XXII.

On the proximate Causes of the Primary Currents of the Ocean.

In addition to the disturbances produced in the water of the ocean by tidal action, there are extensive movements of it that are known by the name of Oceanic Currents. Different opinions have been entertained respecting the causes of these currents, but they have generally been ascribed to the rotation of the globe on its axis causing the surface of the earth to move eastward, faster than the water which is contained in the bed of the ocean. The influence of wind on the surface of the water has been occasionally recognised, but mostly as a modifying cause, affecting only the surface and the water immediately under it.

For instance, in Lizars' *Atlas*, it is said—"Besides the tides there is a regular motion of the waters of the ocean, which carries them from east to west in the tropical regions, and as far as 30 degrees of north and south latitudes in the same direction as the trade winds, but contrary to that of the rotation of the globe. According to Malte Brun, the globe, moving with velocity towards the east, leaves the waters of the tropical oceans always a little behind; and hence they seem to move towards the west with a rapidity proportioned to the superior velocity with which the solid parts of the earth really move towards the east." And the writer of the *Atlas* remarks—"Whatever may be thought of this theory, which, it must be confessed, is somewhat fanciful, the fact is certain as to the existence of these currents or movements, by which

the waters of the sea are carried without any impulse of the wind or tide into a particular direction." "Thus the Pacific Ocean flows from east to west with a motion powerful in proportion to the vast and uninterrupted extent of that sea. This main current, in its motion westward, is impeded by an immense archipelago of islands and sub-marine mountains. It forces its way into this labyrinth, and then forms a variety of currents."*

In the same work, in speaking of the Atlantic currents, it is said—"The great western current of the Indian Ocean, after passing the Cape of Good Hope, advances across the Atlantic to the American shore; and being opposed by this great barrier the waters divide, and are turned in different directions by the peculiar configurations of the coast. One part makes its way through the Straits of Magellan to the Pacific Ocean; the other stream is better known, it being the great current of the Atlantic Ocean, which is turned northward about the 8th degree of south latitude, and extends towards the eastern coast of America. It is extremely rapid;—it prevails from the 30th degree of north latitude to the 10th degree of south latitude, beginning at from twenty to thirty leagues from the coast of Africa, and extending over all that sea in which the Antilles are scattered. There is a third great current of the Atlantic Ocean, by which its waters, in their progress westward, are carried violently into the Gulf of Mexico, and there, being collected and concentrated, they rush with rapidity through the Bahama Channel."

In the *Penny Cyclopædia*, where the general opinion on the subject is also given, it is said that "Humboldt, ascribing the formation of these currents to the rotation of the earth, calls them 'currents of rotation.' But he does not distinguish between the proper currents and the drift-water, which latter produces a slight western current on the surface of the ocean

* Lizars' "Atlas," p. 35.

between the tropics. This latter motion is indeed probably caused by the united effects of the rotation and the trade winds, on the wide-expanded surface of the ocean. The small degree of velocity in this current, however, shows that the stronger currents near the equator cannot arise from the same cause. Rennel thinks that the equatorial currents are caused by the accumulation of great masses of drift-water near the equator, by the north-easterly and south-easterly trade winds. But this opinion will be found inadmissible, when it is considered that such accumulation could only produce a superficial current; and these currents are not superficial, but go to a great depth." Again, in the article on this subject in the *Encyclopædia Britannica* it is said, that "in the sea, currents are either natural and general, arising from the diurnal rotation of the earth about its axis; or accidental and particular, caused by the waters being driven against promontories, or into gulfs or straits."

Thus, all these writers concur in representing the rotatory motion of the earth as the great cause of the oceanic currents that are found within the tropical regions. This rotatory motion causing the tropical parts of the land to move eastward at a high velocity, it is assumed that the waters of the ocean must be left behind. But for this assumption there does not appear to be any sufficient reason assigned, nor indeed is any plausible reason given, unless the alleged depths of the oceanic currents can be considered one. But it will be admitted that the weight of the water will cause it to press on the solid bottom of the sea, however deep or shallow the water may be, with a force proportioned to the weight; and it has not been shown that that weight will be insufficient to enable the solid earth to carry the fluid water with it, and thus to cause both to move with a velocity which, with reference to our present subject, may be considered equal. The assumption, therefore, that the water will be left behind the land, being unsupported by specific evidence, may at present be

treated as unproved. Of the facts that are furnished there is no doubt, as these oceanic currents are well known to exist; it is therefore of the causes alone that we have to treat, and the great cause is stated by these writers to be the rotation of the surface of the globe making the solid land move faster than the liquid water that rests upon it, which is therefore said to be left behind in its rotation, making an apparent current.

Now, if the rotation of the solid earth really left the water behind, we should have an apparent western current flowing across every part of the open tropical seas, and therefore across not only the Pacific and Atlantic, but also across the Indian Ocean, near the equator, say from Sumatra to Ajan and Zanguebar on the eastern side of Africa. This ocean is as wide as the Atlantic near to the equator, and therefore would allow the land to pass eastward from the water, if it could so pass, quite as well as in the Atlantic. But there is no such current in this part of the Indian Ocean; on the contrary, the currents that are found in this locality flow towards the east rather than to the west.

On the opposite side of the Continent of Africa, however, there is a very decided oceanic current, but it flows from the west to the east, just in the opposite direction to those "currents of rotation" of which we have been speaking. This current is generally spoken of as being very extraordinary. Lizars says of it,—"Along the western coast of Africa some singular currents prevail. Between the 30th degree of north and the 10th degree of south latitude (the same breadth as the westerly stream that runs into the Gulf of Mexico) an easterly current sets in towards the shore, which has been sometimes fatal to mariners. By this current, vessels, if they approach too near the coast, are drawn into the Gulf of Guinea, out of which they experience the greatest difficulty in making their way."

Other writers speak of this current in the same manner. One of them says,—"This current, which is known by the

name of Fernando Po, is said to be so strong as to impel vessels powerfully towards the bay, when they happen to come too near the coast. Its strength is such that a vessel may, in two days, go from Maura to Rio de Benin, distant 150 leagues; and the time required to return is about six weeks."*

In this locality, the land on which the sea water rests, so far from moving towards the east with greater velocity than the water of that sea, most undoubtedly must move with a less velocity, as it allows the water to proceed eastward so much faster than itself, as to constitute that water a strong current running eastward into the Gulf of Guinea. Thus on both sides of Africa within the tropics, the oceanic currents, where any exist, move in a direction the opposite to that which would be found if the theory of which we are speaking were true. There are many other currents that furnish practical evidence of the erroneous nature of that theory; but it is desirable that we should in the first instance direct our attention to those great western currents that have been named, and to the causes which, it may be presumed, really produce them.

In one of the extracts that have been given, some influence is assigned to the winds that blow over the tropical seas, but they are said to produce only a superficial effect on the body of the water, and it is positively asserted that they do not produce the great and deep currents of the ocean. It is necessary, therefore, that we should advert to the nature of the action of the wind, on water over which it is passing, in order that we may see the force of this assertion. The atmosphere presses with a weight of say 15 lbs. on each square inch of the surface of the water, and when that atmosphere is in motion as a wind, it continues to press with the same weight, and by its friction must tend to impel the water forward in the direction in which the wind is blowing. The immediate effect

* See Chart, (Plate 5,) with arrow showing the direction of the current.

of this wind, as is well known, is to cause a slight ripple on the surface of the water: and afterwards in a short time, and in proportion to the velocity of the wind, to produce small or large waves. The waves when formed present a rougher surface for the wind to act on, and they enable it more effectually to force the water forward in a horizontal direction. Now this force being continued for a long time, and acting over a large extent of surface, is, it is contended, capable of produciug a great general result, in communicating motion to the waters of the great oceans.

It is known, too, that the gases which constitute the atmosphere, to a certain extent penetrate the body of any water on which they rest; the atmosphere may therefore be considered not to press altogether on the surface of the water, but to some extent on that portion of the gases which the body of the water contains. Now, when the atmosphere over the sea is put in motion and becomes a wind, it must have a tendency to carry with it, not only all the air that is above the surface of the water, but also that portion which has penetrated the body of it, and that is below the surface. How far this circumstance may cause the wind more effectually to carry with it the water over which it is passing may not be known, but the tendency of a wind to produce such an effect is sufficiently apparent.

That wind, such as has been described, acting on the surface of water, will put it in motion and to some extent produce a current, is so evident, that it must be and indeed is admitted: but it is said that currents produced by this cause are superficial, whilst the tropical currents are of great depth. The depth of the current, however, may depend on the velocity with which the wind blows, the constancy of its action, and the extent of water on which it acts. When the wind first presses on the water, it appears to act on the surface alone; but when that surface is put in motion, the upper water, while in motion, presses on that which is lower, and carries

it also forward in a horizontal direction; and this pressure of the water while in motion is propagated to greater depths, so long as the pressure of the wind on the surface is continued. For the wind, moving as it does with greater velocity than the water, exerts its force in every successive instant of time, like gravity in the descent of bodies, and that force is added to all the previous effect that had been produced. And over a wide ocean, there is no reason to be assigned that the pressure of wind, acting constantly on the surface of the water, should not give motion to that water even at great depths.

The tropical trade wind of the Pacific Ocean, in which exists one of the great oceanic currents that have been named, is first found moving slowly near to the Galapagos Islands, in say about 90 degrees of west longitude, where it produces but a slight effect on the water of the ocean: but it continues blowing westward, and generally with increasing velocity, over not less than say 120 degrees of longitude, or 7,200 geographical miles;* there is, therefore, over this ocean, sufficient space to permit the action of the comparatively rapid wind on the surface of the water to press that water forward with increasing rapidity, and to greater and greater depths; and the current thus created, by the wind alone, may, it is considered, be found to extend to great depths.

Another wind of the tropical regions,—the trade wind of the Southern Atlantic, appears to have its origin in so remote a part as near the western coast of Australia. From between say 20 and 30 degrees of south latitude, wind blows from the east across the Indian Ocean, and it apparently carries with it the waters of the ocean, as an oceanic current sets on Madagascar and the southern part of Africa. It then passes across the Southern Atlantic, as a south-east wind, extending to the coast of Brazil, followed throughout its course by the water of the ocean. A part of this water, being impelled

* See Chart, with arrow.

by the wind through the Caribbean Sea and into the Gulf of Mexico, is there accumulated and raised to a higher level, until it finds an outlet in the channel between Florida and the island of Cuba, along which channel it passes as the well-known Gulf Stream. Now wind, acting constantly on the surface of water as these trade winds do, and over the extent of two great oceans, must, for the reasons that have been given, be considered fully able to set that water in motion, not merely on the surface or a little below it, but to a depth quite equal to that at which the currents are found in the Southern Atlantic, the Caribbean Sea, or the Gulf of Mexico.

The eastern trade wind of the Northern Atlantic, in like manner, traverses the surface of the part of the ocean that lies between the Canary Islands and the West Indies,* taking water with it, which water, in conjunction with that which comes from the Southern Atlantic, is forced into the Gulf of Mexico; and the water of these two currents is, by its accumulation and acquired velocity, carried northward to the bank of Newfoundland, from which it is deflected across the Atlantic.†

It is evidently the same kind of force, namely, the force of the wind acting on the surface of water, that produces the oceanic current that has been already alluded to, in the Gulf of Guinea, which, to the surprise of the rotatory theorists, flows in an opposite direction to those just mentioned. A strong wind to the west here traverses only a moderate extent of sea, and blows into this gulf towards the shore; yet this wind, short as is its course, evidently forces the water forward and creates the oceanic current, no other cause being found to

* See Chart.

† It is stated by Milner, (p. 363,) that it has been calculated that the water in the Gulf of Mexico is raised by the force of the current which extends say 4,000 miles from the Cape de Verd Islands, no less than 325 feet above its level when at the islands; a height which will cause it to be impelled, by gravity alone, with considerable force through the Straits of Bahama.

produce it in this case. But if wind, by blowing over so comparatively small an extent of sea, can produce such a rapid oceanic current as that which exists in the Gulf of Guinea, there can be no reason given that the same agent should not, by passing over the Pacific, the Indian, and the Atlantic Oceans, produce strong currents in them. There is said to be another current in the Pacific Ocean, between the 4th and the 10th degrees of north latitude, which flows from some distance in the open ocean into the Bay of Panama, and therefore in an opposite direction to the great eastern equatorial current; and this western current must move eastward faster than the land on which it presses. The only agent that can be traced, as likely to produce this current, and which no doubt does produce it, is the wind which blows off California and Mexico into the rainy bay and country of Panama.

It has been long observed that wind blowing over water towards land, acts on water which is obstructed by the land, with a force sufficient to raise it to a considerably higher level than it would otherwise attain. This has been particularly noticed in the river Thames, where a strong wind acting in the same direction as the flowing tide, raises the water much above the proper tidal elevation, whilst the wind acting in the opposite direction to the tide produces a contrary result: the same effects are experienced in the Severn. In the canal between Runcorn and Manchester, which has a level of considerable extent, the wind, when it blows strongly from Runcorn, raises the water above the true level at Manchester. The same kind of effect is produced in the Forth and Clyde Canal. When the wind has for some time blown strongly from Suez, at the head of the Red Sea, it is said that the water of that sea has been forced southward to so great an extent, as to leave the bed of the sea almost fordable, though, at other times it is deep. Mr. Taylor, the astronomer at Madras, informs us that "the north-east monsoon sets in at that place about the 19th of October, and along with the

wind a current sets along the shore. It reaches its maximum velocity about the 1st of November, running then three miles an hour. During this interval the sea, on a squally day, rises two and a half feet above and sinks two and a half feet below its mean level, and, in the case of a gale of wind, it may possibly reach to double this amount." "On the 21st May, 1833, a terrible storm raged in the Bay of Bengal, near the mouth of the Hoogly, when the tide, at the mouth of that river, rose more than twelve feet above the ordinary height of the springs." These are a few of the numberless instances which might be adduced to show that wind, acting on the surface of confined water, produces upon it great effect in raising its level; but when there is ample space for the water to move forward, the wind readily produces a current, and it is evident from the nature of the force that is in action, that that current will, in deep water, extend to depths proportioned to the length of time that the wind has acted on the water which is in motion.

There are parts, other than those which have been mentioned, where winds evidently create oceanic currents. One blows from the south along the western coast of South America, and an oceanic current is found moving with it, increasing in velocity with the increase of the wind, and carrying comparatively cold water even to the equator. This current of the ocean runs from south to north, and not from east to west, as the so-called rotatory currents do; the surface of the land, therefore, moving easterly, faster than the water resting on it, cannot account for this current, which must be produced by the wind. There is another extensive current which is thus described:—"In the Indian Ocean we find the well-known current that runs from south to north, from the west coast of New Holland, (Australia,) and from the Island of Sumatra, as far as the bottom of the Gulf of Bengal."* It also "impels one of its branches through the Strait of India;

* See Chart.

thence it runs with great violence into the Chinese Seas, and was found by La Perouse to be of great strength in the Sea of Japan, and in the Channel of Tartary."* This great current, it appears, has to cross the equator near Sumatra, from which part there is open sea extending say three thousand miles to the coast of Africa; and if the water of the ocean were here left behind by the land, it would have an apparent current westward, that is, in the direction of Africa. But we see that it runs not west but north, first into the Bay of Bengal, and then it passes to the east through the Indian and Chinese Seas. This extensive oceanic current, therefore, which directly crosses the equator, and which, in the Indian and Chinese Seas, runs eastward, and therefore rotates faster eastward than the land, cannot be water left behind by the land.

But, it is in those parts of the world where the direction of the oceanic currents changes with the season, that we have the strongest proof of the errors of those writers who attribute the currents to the rotatory motion of the earth. That motion is always the same, quite independent of seasons, and any effect really produced by it would be undisturbed by changes in the seasons; this would be more particularly the case within the tropical regions, where the rotatory motion of the surface of the earth is the most rapid. Now, over the Northern Indian Ocean, the Bay of Bengal, and the China Sea, the south-west monsoon prevails during summer, and the north-east monsoon blows during the winter. And the oceanic currents of these parts of the world are found to obey, not the rotatory motion of the earth, as they should according to the rotatory theory, but for the time the influence of the prevailing wind,—changing regularly with the change of the season. Thus we are told by one writer that "between Cochin China and Malacca, when the western monsoon blows, that is, from April to August, the current sets eastward against the general motion. In like

* Lizars' "Atlas," p. 35.

manner, for some months after the middle of February, the currents set from the Maldives towards India on the east, against the general motion of the sea. Varinius says that at Java, in the Straits of Sunda, when the monsoon blows from the west, that is, in the month of May, the currents set to the eastward, contrary to the general motion. Between the islands of Celebes and Madura, when the western monsoon sets in, that is, in December, January, and February, or when the winds blow from the north-west or between the north and west, the currents set to the south-east, or between the south and east."*

Davidson, in an account of his voyage in this part of the world, says,—"From April to September the south-east monsoon blows in Torres Straits, and the western monsoon prevails during October and the five following months, and these last winds blow so strongly as to close the passage of those straits," (from the Pacific.)† He also further states that "the barrier reef extends from the coast of New Holland (Australia) to that of Papua, (or New Guinea,) with numerous gaps and entrances in it, which appear to be kept open by the current that for six months in the year runs through them from the Pacific to the Indian Sea, and in the contrary direction during the other six."‡ It thus appears that during one half of the year the wind blows from the Pacific Ocean through these straits, and then the oceanic current runs through them from the Pacific; but during the other half the wind blows from the Indian Ocean, and then the current runs with it from that ocean. If the solid land, in its rotation towards the east, left the water behind, and gave it an apparent motion towards the west, it most undoubtedly would run westward here from the wide Pacific Ocean, in the winter as well as in the summer,—from October to March, as well as from March to October,—seeing that the rotatory motion would always produce precisely the same effect. But as it does not do so,

* Rees' "Cyclopædia." † See Chart. ‡ See Chart, and Davidson, p. 214

we must conclude that it is the changing wind that produces the currents which so uniformly change with it.

These accounts of the alterations of the oceanic currents with the change in the direction of the wind, are mostly given by writers who supposed that the rotation of the earth was the great general cause of the currents, and they speak of the altered direction of the water in the particular cases with surprise. There is, therefore, every reason to place confidence in their accounts; and their statements show not only that wind can produce motion in the water of the ocean over which it passes, but that it produces the motion in a short time, and while passing over only a limited space. It is always soon after the wind changes that the ocean current changes, and many of the currents run with great force in a direction exactly contrary to that which is erroneously supposed to be their natural direction, consequent on the rotation of the earth. But if within these comparatively limited spaces wind can soon put water in rapid motion, it is sufficiently evident that the same wind, acting on the surface of broad oceans, and for a much longer time, is capable of producing proportionately greater effect, and it may therefore be admitted to be able to create the currents that are found in the widest and deepest seas.

It may, no doubt, be easily imagined, by those who are so disposed, that rapidly rotating water, such as that which passes northward from the Gulf of Mexico, takes with it its swift motion, and therefore that it must proceed eastward faster than the land over which it is passing. But the water of this secondary current, being accumulated in the Gulf of Mexico, and raised to a great height, is evidently forced to run in the easterly direction that it takes by the form of the western boundary of the Atlantic basin, which, in its more northern part, extends to the eastward. From the southern extremity of Florida, where the gulf stream has a rotatory velocity of, say, about nine hundred miles an hour, it runs nearly parallel with the American shore until it reaches the latitude of 46°,

which has a velocity of not more than, say, seven hundred miles an hour. And it is only when it encounters the great Bank of Newfoundland that it turns decidedly to the east, and flows across the Atlantic to the western shores of Europe. This current, therefore, must be impelled northward from the Gulf of Mexico, by a force existing in that gulf, and through the impulse given to it, it evidently proceeds in such direction as the basin of the Atlantic permits, until it is deflected eastward, and finally it returns southward into the tropical current that runs from Africa to the West Indies, which is created by the north-east trade wind.

On the opposite side of the equator we have a different state of things. The whole of the great current of the Southern Atlantic does not run into the Gulf of Mexico, but is divided by a projecting point of the Brazilian coast, in, say, about the sixth degree of south latitude, into two portions, of which one only runs through the Caribbean Sea into the Gulf of Mexico; the other passes southward along the coast of Brazil and by Eastern Patagonia to the Straits of Magellan. Now, the water of this secondary current, when in the sixth degree of latitude, must be presumed to have acquired the velocity of the land in that parallel, which is, say, nearly one thousand miles an hour. But from this point it is impelled southward until it reaches the latitude of 54°, which has a rotatory velocity of only about six hundred miles an hour. But this water, instead of taking with it the high velocity of the sixth degree of latitude, which would soon have carried it very far to the east, runs westward through about 30° of longitude to the latitude of 54°. It thus appears that the impetus which this water receives from the wind, in crossing the Atlantic from the Cape of Good Hope to Brazil, is sufficient to carry it from a part where it has a surface velocity of one thousand miles an hour to another part where it has a velocity of only six hundred miles an hour, without bearing with it any of the swifter eastern motion, but, on the contrary, actually moving

westward. It follows, that this tropical water loses its high rotatory velocity, as it passes southward, so readily and completely, through its pressure on the land which constitutes its bed, as to allow the acquired force of the current that had been created by the wind to carry it in the opposite direction to that in which the altered rotation of the latitude would be inclined to carry it. It is, indeed, sufficiently evident that the obstruction presented by the eastern coast of America alone prevents the water from going more west than it does before it reaches the Straits of Magellan, notwithstanding that it passes into latitudes which have successively slower rotations. The motion of the surface near to the equator is nearly one thousand miles an hour, but the wind impels the water in the current southward after the average rate through its whole course of, say, not more than one mile an hour; and it is evidently the slow motion southward that allows the water, by its pressure on the bottom of the ocean, fully to acquire the reduced rotatory speed of the latitudes over which it passes; and this fact is in harmony with those which have been already given, as well as with many others that might be adduced.

Water from the China Sea, which is impelled northward towards Japan and the Tartarian Channel, is forced to pass along ocean boundaries, not westward like that off Brazil, but eastward, like that off North America, and therefore it must move eastward faster than the ocean bed on which it presses; but there is no reason to suppose that it is carried to the east faster than the land by previously acquired high rotatory velocity, seeing that the same motion, evidently acquired by the action of wind, that here carries the water to the east, impelled it westward off the South American coast. We are not at liberty to suppose that one cause produced the western current off America, and that there is another and a different cause for the eastern current off Asia; wind, and the shape of the shores, seem alone able to produce both currents, and therefore we have to conclude that they produce each.

Currents in other parts of the ocean show, in a palpable manner, the influence of wind in producing them. Welsted, in his account of Arabia, says,—"There are few portions of the globe where the results of calms and strong currents are felt conjointly with more effect or in greater degree than in the Gulf of Aden. These currents would appear to obey no certain laws; sweeping up the coast of Africa to the northward at a velocity of sometimes eighty miles a day, they impel a body of water into the Gulf of Aden, increasing the level of its waters until a north-westerly breeze forces them to the southward at a rate of almost equal velocity." It is pretty evident that wind from the open Arabian Sea must have forced the water into the gulf before the north-westerly breeze carried it out, and it is certain that rotatory velocity could not produce such intermitting movements.

An oceanic current flows from the Antarctic Sea near Victoria Land, to Tierra del Fuego, which is from a south-western towards a north-eastern part of the globe, consequently from a slowly rotating to a quicker rotating latitude. At the point of its departure from Victoria Land the rotation shall be, say, three hundred and forty miles an hour; and when the current reaches Tierra del Fuego, it is over a part that rotates, say, six hundred miles an hour. But does the quicker rotating land over which the water passes leave that water behind? No, it does not. If it did, the water would run towards Australia or the Indian Ocean; whereas it passes eastward through 50° of longitude, and consequently moves eastward faster than the land on which it presses, until it reaches the great region of condensation about Tierra del Fuego; towards which region, it will be recollected, winds blow, passing over the same line as the oceanic current.

The remarkable wind that blows along the western coast of South America has been already noticed; and that wind evidently takes with it a current of cold water to the equator. Now, as the solid land does not leave this water behind, the

water must experience no difficulty in increasing its rotatory velocity from, say, six hundred miles an hour, the speed which it had at Tierra del Fuego, to the one thousand miles that it attains at the equator. On the other side of the equator, too, along the coasts of California and Mexico, in the rainy season, a strong north-west wind blows towards the Gulf of Panama, and then an ocean current travels with the wind. These two oceanic currents from south and north heap up the water of the Pacific near the equator, perhaps enough to enable gravity to make it flow westward into the open Pacific Ocean. But it should be observed that in this, as in former cases that have been adduced, both the wind and the water that pass from California to the Bay of Panama go from the northern tropic towards the equator with greater velocity than the parallels of land over which they are passing, as the wind and water move towards the east faster than the land on which they press.

Most writers assert that the western tropical current of the Pacific is produced by the land moving eastward faster than the water, thus leaving the latter behind: this I have already shown is not the real cause of this current. There is, however, special evidence to prove the fallaciousness of the theory combated, in the fact, that at a particular season the wind blows in a direction the opposite to the usual one, over a large part of the Pacific within the southern tropic. This takes place when the sun is far south, and consequently when it has greatly heated the southern hemisphere and vaporised much water in it, which vapour is largely condensed about islands, and on the continent near Panama and Guayaquil; and although the wind does not appear to be sufficiently continuous to produce a strong ocean current in the open sea, many notices by navigators indicate that it disturbs the regular eastern current, especially about islands.

There is also an important consideration with relation to this subject. When water passing from south or north arrives at the equator, it is conceivable that at first it may to a small

extent be left behind by the quicker rotating land. Yet its pressure on the land must very soon make it acquire the velocity of the equator, when it would move with the land at its full speed. But the eastern equatorial current of the Pacific, like that of the Atlantic, is found running not merely over the whole ocean, but as it proceeds westward it runs with increased velocity, showing that the cause which is in action remains in operation over the whole longitudinal extent, and it produces increased effect on the current as it approaches the Eastern Archipelago.

We have, indeed, abundant evidence that on every part of the globe, from the equator to the poles, whatever may be the rotatory velocity of the part, both the water and the air pressing upon it readily acquire that velocity, and, with reference to rotatory motion, move with the solid surface nearly as if all were at rest. The cause that disturbs either the air or the water acts upon it as if no rotatory motion existed. And if the sun be supposed to move round the earth, as was once believed, warming the different meridians successively, as they are now warmed through the earth's motion, it is contended that the air and the water would move in about the same way that they do at present. The air would be more or less disturbed by the intermitting action of the solar heat, which would put it in motion through the change of temperature in the twenty-four hours. Water would also be vaporised as at present, and the vapour would rise and penetrate the gaseous atmosphere, and some of it would be carried up elevated land, when condensation would take place, just as it does now; and both vertical and horizontal aërial currents would be created as at present. The winds would press on and put in motion the water, and the different areas of condensation would bring air from other parts according to the degree of vacuum produced, drawing against and crossing each other; and the water on which the wind pressed would obey that pressure until its own gravity

become a counteracting force. In short, it is contended that all the atmospheric and primary oceanic currents would be substantially the same as at present. And in tracing the causes of both these currents, as they are now found on the globe, it is unnecessary to advert to its rotatory motion, as they are not affected by it to a sufficient extent to require notice.

In speaking of water having a natural level, gravity alone has been presumed to determine that level, and it will be readily conceived that when such a body as the atmosphere, moving on the surface of water, forces the water above its natural height, gravity immediately begins to act to bring it down from that height;—and where the wind is constant the two opposing forces may be always in action, the general result being such a level of the water as will be determined by the two forces,—wind raising the water above its natural level until the inequality enables gravity to act. But in the actual state of our planet, it is not strictly correct to represent gravity as the only force that is opposed to wind. The distance of the equatorial surface of the ocean from the centre of gravity is, say, about thirteen miles more than that of the polar surface, and were gravity the only force that was constantly in action, the water of the equator, notwithstanding any influence of wind, would run down to the poles, just as water will ordinarily run down a hill. But this is prevented by the centrifugal force consequent on rotatory motion, which to a certain extent counteracts the attraction of gravitation; and the natural level of the water of the ocean, in every latitude, when undisturbed by wind, is determined by the joint action of gravity and centrifugal force. These leave the water at the equator say about thirteen miles higher than it is at the poles, and in the intermediate parts high in proportion to the strength of the centrifugal force in each latitude. In tracing the influence of wind, however,

in raising the level of the ocean, it is more simple to speak of gravity alone as determining that level, it being understood that centrifugal force produces its due effect in each latitude.

Slow oceanic currents are by writers generally supposed to flow from the polar towards the tropical regions, seeing that icebergs, which must have been formed near the poles, are found at great distances from them, until they are dissolved by high temperature. These icebergs, however, often seem to be carried along by an under-current, as that which is found at the surface is sometimes moving in the opposite direction to the icebergs. We have seen that in the northern hemisphere the winds that blow over the ocean are generally those that come from warmer latitudes, bringing much vapour with them. These must, by their friction, to a certain extent impel the water towards the polar regions, as is found to occur off Norway. The water thus carried forward to the polar regions would in due time be heaped up above its natural level; and should it be unable to return at the surface by any outlet, it would be compelled, in its effort to re-establish an equilibrium, to pass somewhere by an under-current. The winds which pass northward over the Atlantic and Arctic Oceans do not return over the sea, but pass towards the equator over the land of Asia, and consequently do not force the water back in any part, but leave it to return in some other way, and it may be that it returns through the action of gravity by an under-current. Similar winds in the winter pass over the North American Continent. In the more open ocean of the southern hemisphere, the influence of wind is not so palpable as in the contracted Northern Atlantic; but recent observations have shown that vapour produced by evaporation in warmer latitudes is carried towards the south pole, where, on reaching elevated land, it is condensed in large quantities, causing winds to blow towards

that part, as they do towards Norway and Spitzbergen in the north.

These latter winds, it may be presumed, press the water into the polar basin and raise it above its natural level. That this takes place may be inferred from many accounts that we have of these parts, the sea there having been always noticed for its winds blowing towards Nova Zembla and Spitzbergen. In the winter they must penetrate far into the polar basin, bearing with them a high temperature, as may be seen in Dove's *Charts of Isothermal Lines.** And the surface water that must be forced by the winds into this basin has no known outlet but at the narrow channel of Behring's Straits, unless it makes its way by an under-current. Between Spitzbergen and the pole, in about the 83rd degree of latitude, Parry found, in the summer, a current setting southward, which must, therefore, have come from the direction of the pole; but it appears that this current was not felt on the surface much farther to the south. Judging from the great extension in this part, both northward and eastward, of high temperature in the winter, there is a probability that a south-west wind carries an oceanic current across the polar sea, and raises the water in it above the natural level. Water seems to pass eastward from Baffin's Bay into the Atlantic Ocean, taking icebergs with it; but this water may possibly have come from Spitzbergen round the north of Greenland, across the polar sea, and through the channels about Melville Island, in that way entering Baffin's Bay, and passing through it to the Northern Atlantic. This is only conjecture, but further information respecting the currents in this part is likely to be soon obtained. We, however, already know the fact, that ice is brought from the polar sea to the northern shore of Iceland, and heaped up in its bays, and this ice must have been brought from

* See Isothermal Lines on Chart.

the north either by the wind or a polar current. If by the latter, it must pass towards the south between Iceland and Greenland to Davis' Straits, where it may join that which comes out of Baffin's Bay, and which bears icebergs still farther south, leaving the part of the ocean nearer to Norway open to the southern winds that penetrate to Nova Zembla.

Near to and within the Antarctic Ocean we find facts similar to those described in the Arctic, allowing for local influences. Icebergs in the southern hemisphere float into latitudes nearer to the equator than they do in the north—it is said even to the latitude of the Cape of Good Hope, showing, that whatever may be the current there on the surface, there is one at a depth reached by icebergs that are passing from the Antarctic Ocean towards the equator. The voyages of Sir J. Ross and others have shown that winds, apparently north-west, blow strongly towards the lands that exist near the south pole, and we have seen reason to believe that they must produce on the surface of the ocean corresponding currents. The water of the ocean near the pole being thus raised above its natural level, the upper water will press on that which is below, and force it to return towards the tropics as an under-current.

But it may be asked, what becomes of the air that passes thus from warmer to colder latitudes? And here our information, it must be admitted, is not sufficiently full to allow a complete answer to be given: we are not, however, entirely without knowledge of the subject. It is well known that winds blow both in summer and winter, but particularly in the latter, from the polar sea over the land of the eastern hemisphere. They blow over Siberia, Russia, Tartary, and Persia, towards the Himalaya Mountains. Others make their way over Europe, and it may be over Africa, to feed the north-east trade wind of the Atlantic, returning north by

the Arctic Ocean to complete the circuit. In the southern hemisphere, the air that passes to Victoria Land probably returns in those winds that blow with unceasing force from the south and west to the stormy regions of Cape Horn, and they make their way afterwards along the western coast of South America and across the Pacific Ocean to the great Eastern Archipelago. But it is not necessary here to follow out in greater detail the movements of such a body as air, as we know that wherever the equilibrium of its pressure is destroyed, it will, in consequence of its gravity and fluidity, immediately begin to move—that portion which is heavy always pressing or moving towards that which is lighter. And where the air that is in motion passes over water, it gives motion to that water in proportion to the velocity and continuity of its action.

It has thus been found that all the great oceanic currents which have been pointed out are accompanied by winds; that, although they sometimes move in accordance with the rotatory theory, they at other times run in opposition to it, but they always run in the direction of the wind, and they change as the wind changes. The evidence against the rotation theory may therefore be said to be strong and complete, and that theory may be considered erroneous.

As a consequence of the greater rotatory velocity of the surface of the globe within than without the tropics, it has long been believed that within the tropics the surface of the earth, in its rotation, left the atmosphere behind, and thus produced the eastern tropical trade winds. And certainly, from the greater velocity of the air than of the water of the sea when passing from a slower to a quicker rotating latitude, this was not an unreasonable conjecture; the Hadleyian theory of winds was therefore plausible. But it has been proved that even the air soon acquires the rotatory velocity of the portion of the globe on which it presses, and is then just

as ready to obey local influences as if both itself and the surface were without rotatory motion.* But if air with its lightness and elasticity thus rapidly acquires the motion of the part of the earth on which it rests, how much more decidedly must heavy and comparatively inelastic water do so? Yet it is very probable that the opinion so generally adopted, that the tropical trade winds were caused by the earth leaving the air behind it, countenanced, if it did not give birth to the belief, that the solid earth, in its rotation, left the waters of the ocean behind. I am not aware of any proof having been furnished of the superior rotatory velocity of the bed of the ocean, as compared with that of the water resting on it. It appears to have been voluntarily assumed, in order to assign a cause for the great oceanic currents, as no other adequate cause could be found. But when it is seen that wind has sufficient power to produce, not only the great eastern oceanic currents, but also the other currents which run in different directions, and with great velocities, and that wind is always in action wherever the primary currents are found, such an assumption becomes unnecessary and may be discarded.

The waters of the ocean are partially confined within basins having bottoms unequal in depth, with sub-marine mountains and valleys, bounded by land of irregular forms; and an ocean current created by wind within any basin may obviously have its direction altered by a sub-marine valley or mountain, just as the direction of wind itself may be changed or modified in passing through a valley above the level of the sea. And when a force like the action of wind, in some particular locality, raises water much above its natural level, as it does in the Gulf of Mexico, the gravity of the water immediately acts to restore the equilibrium of pressure, and may thus

* See the various arrows on the Chart which point out the winds as well as the primary currents of the ocean.

produce new currents. It is not, however, the object of this Essay to pursue secondary oceanic currents through their various courses,—that object having been to point out the real primary cause that puts in motion the waters whose movements constitute the great currents of the tropical seas, which are the great currents of the ocean. And this cause it is contended is the Wind,—which, itself produced by condensing vapour heating the atmosphere in particular localities, blows towards those localities, taking the water of the ocean with it, uninfluenced to any appreciable and palpable extent, by the rotatory motion of the surface of the globe,—thus showing that *Wind* is the real cause of the great oceanic currents.

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HARBOURS, DOCKS, AND COAST ENGINEERING.

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ON

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"Of the importance of the subject there can be no doubt, for we find from the earliest ages, that the nations holding the command of the sea were generally the most powerful, and studied with the greatest care the art of preserving and improving their Harbours. As an example we may mention the Phœnicians, who, from merely possessing a narrow strip of barren land along the coast of Syria, became the most wealthy and the greatest of nations, and were only subdued [illegible]

pelled to bring the whole power of the East, or it may be said of the world, to vanquish them. Again, the Greeks, by their command of the sea, maintained their independence with a mere handful of men against the millions of Xerxes. Again, the Carthaginians made head against and almost conquered the mighty Romans, who only recovered their ascendancy, and ultimately overwhelmed their formidable adversary, by acquiring the command of the ocean; and although the Romans were naturally averse to the sea and the pursuits of commerce, yet, feeling that the very preservation of their empire depended upon their maritime superiority, they devoted the greatest care and attention to the perfection of their Fleets and Harbours, as the magnificent remains I shall have occasion to mention, in Italy and other places, afford ample testimony. These works evidently prove that the Ancients had made considerable progress both in the theory and practice of Marine Architecture.

"I have endeavoured to select a series of examples from almost every country, from the earliest dawn of civilization to the present time. Each example is complete in itself, and is accompanied by a statement of the geological and geographical features of the coast where it is situated—the winds—the tides—the currents—the soundings—the nature and formation of the rocks by which it is surrounded—the state of the place before any works were executed—the history of the various works executed from time to time—the effect of them;—and where they have failed, the causes of failure are explained, and, as far as circumstances will permit, the remedy best adapted to the nature of the case is pointed out: by this means we obtain the results of experience, which is the most satisfactory of all proofs. We have the record of facts to guide us, and by knowing the causes which have produced certain effects, we can apply them to other similar cases, and thus, if we cannot restore things to their original state, we can stop and prevent the evil from proceeding further; and, in order to derive the greatest advantage from each example, conclusions and general principles are deduced in conformity with them.

"The same plan is pursued as regards the particular kind of workmanship and materials best adapted to each example, whether of wood, stone, or iron, and the mode of carrying it into effect, not omitting at the same time the important item of cost; and as far as space will allow, original documents, reports, and opinions are given, so that the reader will be able to draw his own conclusions and form his opinion accordingly. I have also endeavoured to institute an examina-*tion and comparison between the various examples under the different heads of 'Design,' 'Construction,' and 'Result,' with a view to select*

extremely difficult to draw a correct parallel, or to lay down principles which shall be generally applicable, for each case may require a different mode of treatment, which can only be ascertained by an exact study and investigation of the respective local circumstances."

With this brief explanation of the plan and object of the Work, it is now submitted to the notice of the British and Foreign Governments, to Professional Engineers, and others of all nations who feel interested in the perfect construction and maintenance of Docks and Harbours,— so indispensable in the formation and equipment of naval armaments for the protection of trade and commerce with every portion of the civilized world, and invaluable as asylums for mariners.

It is also submitted to the special notice of the members of those corporate or other bodies upon whom may devolve the conservation and improvement of Harbours, Docks, or Rivers, as a worthy and valuable addition to the records by which they are enabled, either by Charter or by Act of Parliament, to exercise the rights and privileges so conferred upon them.

Mr. Weale deems it necessary to state that the impression was strictly limited to TWO HUNDRED AND FIFTY COPIES, and that an early application should be made by those who are anxious to possess the only work extant, on a sufficiently comprehensive scale, specially devoted to this important department of Civil Engineering.

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LIST OF PLATES—*continued.*

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Ditto, plans and sections of one of the Scouring-Sluices.
Ditto, Locks, and Ramsgate Harbour.
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